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THE EMBRYOLOGY, DEVELOPMENT, AND ANATOMY OF THE NOSE, PARANASAL SINUSES, NASOLACRIMAL PASSAGEWAYS, AND OLFACTORY ORGAN IN MAN

SCHAEFFER

Photographs of cast of nasal fossæ and paranasal (accessory) sinuses viewed from both the right (above) and cranial (below) aspects. From an adult male. Natural size.

f, frontal sinuses; *m*, maxillary sinuses; *s*, sphenoidal sinuses; *e*, ethmoidal cells; *l*, nasolacrimal duct; *nc*, nasal cavity; *c*, right choana (posterior naris); *np*, nasopharynx; *im*, inferior nasal meatus.

THE NOSE, PARANASAL SINUSES, NASOLACRIMAL PASSAGE-WAYS, AND OLFACTORY ORGAN IN MAN

A GENETIC, DEVELOPMENTAL, AND ANATOMICO-PHYSIOLOGICAL CONSIDERATION

BY

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To the Memory
of My
Father-in-law,
Henry Bobb, M. D.
This Volume
is
Gratefully and Affectionately
Dedicated

PREFACE

The object of this monograph is to present a study of the embryology, development and anatomy, both microscopic and macroscopic, of the human nose, the paranasal sinuses, the olfactory organ and certain other ancillary structures. The study had its inception in work done on the maxillary sinus in 1907 at Cornell University. The field of investigation was gradually extended so as to include ultimately the entire nasal region and its immediate environs. The study was continued at intervals at Cornell University (1907–11), at Yale University (1911–14), and at the Jefferson Medical College since 1914.

A number of papers on various phases of the study were published from time to time as the work progressed, and the author now takes the liberty of drawing upon them in this connection; this being alike true for text, diagrams, tables and illustrations. Most of the matter, however, appears in new form and for the first time.

All work must needs be based in part on the labors of the past and the author is not unmindful of the help derived from the recorded observations of other workers in the field. No attempt, however, is here made to review the literature on the subject: had this been done, the size of the book would have been increased far beyond the limits set for it. The aim has been to present a more or less comprehensive account of personal studies and observations on the genesis, development, and anatomy of the nose and its related parts rather than to compile a fairly voluminous literature with its not infrequent diverse conclusions. In large measure, therefore, the descriptions and discussions as set forth in subsequent chapters and paragraphs are based upon researches by the author, extending over a period of years. Likewise most of the illustrations are based upon preparations, reconstructions, and dissections by the author and reproduced either by him or under his directions. Of course, where vital points are at issue or where the author feels that his own observations are inadequate, due reference is made of the work and conclusions of other investigators. Moreover, a certain number of illustrations are after other writers for which proper credit is given in the respective legends.

Seldom, indeed, is it that all phases of a study reach a state of finality. Unfortunately, this is true in the present connection, for in some instances it has become necessary to assume certain conclusions tentatively from established and related facts and the clinical evidence at hand. This, however, seems warranted, for unless we exercise some scientific judgment and imagination no progress can be made. Further study and analyses may affirm or deny the assumptions. It is no easy task, for example, to establish with certainty all the fiber tracts in some neuron circuits. Moreover, when a few hours markedly alter a structure during its developmental stages, it is obviously difficult to have at hand and in serial sections human embryos closely enough graded to demonstrate every possible point that arises in a study such as this. Fortunately, experience has shown that mammalian embryos are of great value in filling in our gaps of knowledge of human embryology and until human embryos of the proper ages fall into the hands of competent observers, it is altogether proper to assume certain hypotheses based upon the study of other and related forms.

In order to consider all portions of the nose and the cognate regions and structures and bring the results of the observations and studies within the limits of an average-sized volume, it was necessary in many instances to omit the records of many detailed observations and to record the essentials only. This is more or less true throughout the work, but especially so in connection with the central olfactory organ and the individual bones that comprise the nasal framework. Important and essential points are, of course, treated in greater detail. Moreover, where brevity of description and discussion would have befogged clearness some otherwise unessential details are recorded. It is, of course, obvious that any one of the chapters and, indeed, in some cases parts of chapters could be profitably amplified into individual monographs. The purpose and plan of the book, however, did not require such amplification.

Despite the large amount of materials studied over a period of years, the author recognizes that this work is incomplete, but hopes the descriptions, discussions and suggestions will be found helpful by physicians and surgeons and undergraduates in medicine.

The author is not unmindful of the many opportunities afforded for the furtherance of this work at the Cornell University Medical College, the Yale University Medical School, and the Jefferson Medical College. Nor of his indebtedness to the Mütter Museum of the College of Physicians of Philadelphia for the privilege of studying certain materials, and to its curator, Dr. Clarence Hoffman, for many courtesies. Moreover,

thanks are due Dr. H. E. Radasch for the preparation of tissues from the author's collection for Figs. 181 and 182, Miss Bremerman for valued help in the preparation of the manuscript and proof-reading, and Miss Neely and Mrs. Schaeffer for certain translations.

The index is the work of Dr. Benjamin Lipshutz.

The author wishes to express his obligations to the publishers for their hearty coöperation and generosity.

J. Parsons Schaeffer.

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Philadelphia, Penna.

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INTRODUCTION

Much productive ground remains unworked in human anatomy and ancillary subjects, despite the unfortunate belief of many graduates in medicine that the study of anatomy has reached a state of finality and that the anatomical field has been fully gleaned of its harvest. When one recalls, however, that modern anatomical teaching and research no longer recognize the unfortunate historic distinction between macroscopic (gross) and microscopic (minute) anatomy; that the human body is now considered from the phyletic, the ontogenetic, the physiologic, the histologic and the gross viewpoints; that modern anatomy is concerned with evolution, heredity and variation, it is clearly obvious that anatomy is no longer restricted to a purely descriptive study, but that its domain has expanded into its proper spheres and that many problems await solution. Even descriptive or gross anatomy is not without its problems, many of vital and practical importance.

It is very difficult and unsatisfactory to approach an anatomical problem without a basic conception of the underlying genetic and developmental history. In order to properly interpret points in the adult anatomy of a region, it not infrequently is necessary to revert to the embryology of the part or region concerned. Many faulty statements extant in the literature are doubtless the result of drawing conclusions from a study of too few specimens, of studying adult material alone, and of errors in interpretation due to the fact that embryologic and adult studies were not carried on simultaneously. A prominent surgeon recently recommended a study and basic understanding of embryology "as one of the foundation stones of surgical training." Be that as it may, it certainly cannot be gainsaid that a knowledge of human anatomy is of paramount importance in a comprehensive understanding and interpretation of both macroscopic and microscopic anatomy, both for the medical student and the physician and surgeon in the practical field.

Variations in the anatomy of the human body are not uncommon, both ontogenetic and phylogenetic. In the former one has to contend with the very important group of human variants generally spoken of as errors in development— congenital defects. There are also progressive and reversional variants encountered. The phyletic variations have to do with the hereditary reappearance of ancestral characters. When one

recalls that "each organism in the course of its individual ontogeny repeats the history of its ancestral development" the appearance of remote characters in man is more comprehensible. In order, therefore, to deal intelligently with variations, one needs, indeed, not infrequently to hark back not only to the developmental history of the individual, but to the ancestral history of man as well.

Entirely apart from the variations referred to above there are the ever-recurring variations in what may be termed the gross anatomic type of a structure, organ, or region of the human body. These too, strictly speaking, are ontogenetic variations in that they result from the differentiation of the individual embryo and lead to the development of a certain anatomic type of the adult body. Some of these variations or types occur so infrequently and are so unlike all others that one must assume that they result from atypical differentiation of the embryo, leading to an anomalous or abnormal structure, organ, or region in the adult. On the other hand, certain variations in the anatomy of many parts of the human body occur with sufficient frequence to justify the establishment of normal anatomic types. This, of course, opposes the conception of an unvarying typical or ideal anatomic type and all departures therefrom as anomalies.

In a general sense only do a large series of human bodies conform in their detailed gross anatomy to a so-called typical form. It would appear from some recent studies that not a few of our traditional ideas found in some clinical text-books in explanation of certain physical signs and other conditions encountered in the human body from time to time are at variance with anatomic facts. Conclusions drawn hastily and not sufficiently verified by extensive anatomic studies are not of infrequent occurrence. The idea of an unvarying typical form in the gross anatomy of the human body appears more or less prevalent in the practical field. There is, of course, great need of extensive study of the various regions, organs, and other structures of the body; the conclusions to be based upon a large number of cadavers. This has been done for some regions and splendid monographs and records are extant on such researches. The work, however, must be extended and ulitmately be made to include all of the important regions of the body. Such studies, if based on a large amount of material and discriminating work, will establish anatomic types. What is desired is not the average nor the mean but the various gross anatomic types of a region, organ or structure, wherever and whenever it is possible to establish such with a fair degree of certainty. After the normal anatomic types are established, the anomalies of the human body will naturally find their proper place, as will also the average and the

mean. This work should be made to include the several ages of the childhood period, the pubertal stage, and that of the adult. It is obvious that such exhaustive anatomical considerations of special regions and organs are not the province of the general text-books of human anatomy, but clearly the function of anatomic monographs.

In studying a given region of the body in an extensive series of cadavers one is profoundly impressed with the ever-recurring departure in the morphology of the part under investigation from the conventional or typal description. This is particularly applicable to the gross anatomy of the paranasal (accessory) sinuses. The primary function of a general text-book of anatomy is doubtless to describe and delineate a "typical" body and to refer to a few variants. It is obviously impossible to do much more within the scope of a single volume. To visualize and understand the anatomy of a typical body is probably also the primary function of a medical student in his initial work in human anatomy.

Unfortunately, however, while there may be a "typical" gross form for regions, organs and structures, it is, strictly speaking, not often encountered in nature. The typical is ideal and the region, organ, etc., as regards shape, size, relations, configuration, etc., very commonly in their actual or real anatomy are variants. It is, therefore, of the greatest importance that the student early recognizes the very common and constant anatomic variations that beset the human body. All that the observant student need do is to witness the dissection of a series of cadavers to have impressed upon him that there is no fixed and unalterable type in very many of the parts of the human body. Unfortunately, however, some students never get beyond the belief and thought that every structure and organ and region conform to an arbitrary and fixed normal, and if there is a slight digression from the conventional text-book description the term "anomaly" is applied. With this erroneous and unfortunate belief they go forth into the practice of medicine: To them the appendix is and must always be in the right iliac fossa; every frontal sinus invades the vertical portion of the frontal bone and if not, there is no frontal sinus present; every liver has the same sized and shaped left lobe and bears a constant topographic relationship to the ventral abdominal wall; all stomachs conform to a single shape; every transverse colon crosses from right to left at a specified plane; the ethmoidal air cells are limited to the ethmoid bone; etc., etc. The far-reaching and direful effects of such faulty conceptions of the anatomy of the human body are so obvious that they need not be discussed here. It, of course, goes without saying that one must primarily have a fundamental understanding of the ground

plan of the human body; however. it cannot be gainsaid that one should be equally cognizant of anatomical departures therefrom.

Despite that the actual anatomy of a region or part is not infrequently a variant of the ideal or typal form (if there really be such) it is possible in many instances to establish normal anatomic groups or types. This is of decided advantage over the method of taking, for example, a series of five hundred or a thousand dissections and establishing from them a composite form and accepting it as the typical or ideal anatomy for the region or organ.

In a general way only should physicians and surgeons accept a so-called typal or ideal form in gross anatomy. Initially, of course, in the study of a patient all regions and organs must needs be approached in large measure from the viewpoint of an "average anatomy" despite the fact that relatively few specimens wholly conform to it. Fortunately, rœntgenology has come to the aid of the physician and surgeon in the determination and delineation of anatomic conformations. Admittedly very many variations are insignificant and can be ignored in the practical field despite the fact that they may be of interest and of great value to the student of embryology and morphology. However, it is a matter of grave concern to the physician and surgeon that many important normal variations and anomalies must be dealt with continually. It is, therefore, clearly obvious that the adherence to a single fixed and arbitrary normal is fraught with danger; since with variations come altered size, altered shape, altered anatomical relations. Morphological variation must necessarily have an important bearing on physical diagnosis, pathology, clinical medicine, and surgery. Indeed, the "anatomic type" always looms up before the man in the practical field as an important factor in treatment and prognosis.

I—GENERAL EMBRYOLOGY AND DEVELOPMENT

THE NOSE, PARANASAL SINUSES, NASO-LACRIMAL PASSAGEWAYS

AND

OLFACTORY ORGAN IN MAN

CHAPTER I

GENERAL EMBRYOLOGY AND DEVELOPMENT

The Proton and Rudiment

The proton[1] of the nose and the peripheral olfactory organ is a paired convex area of the cranial ectoderm near the location of the closed anterior neuropore, and the rudiment or anlage of the organ is represented by a cellular thickening of the corresponding epithelium (sensory epithelium).

The characteristic epithelium of the olfactory placodes or nasal areas is recognizable as early as the third week of embryonal life (4 to 5 mm. embryos). At first the sensory epithelium of the placodes merges imperceptibly with the thin (0.01 mm.) surrounding head epithelium, later thickening with sharp delimitation. These thickened (0.04 to 0.05 mm.) ectodermal placodes are situated on both sides (bilaterally) on the ectal surface of the wall of the forebrain, immediately cephalic to the primitive oral fossa (Fig. 1).

The Nasal Pits

During the fourth week (6 to 7 mm. embryos) the nasal areas become passively depressed by a positive increase in the thickness of the surrounding mesoderm which pushes the overlying ectoderm into relief.

[1] The term proton (*πρῶτος*, first) is here used to apply to that portion of the indifferent surface ectoderm destined to establish the olfactory rudiment or anlage. Proton is not infrequently used in a synonymous sense with rudiment and anlage.

In this manner each olfactory placode becomes surrounded by a fold which is well developed medially and laterally, but deficient ventrocaudally (Fig. 1).

Frontonasal, Nasal, and Maxillary Processes.—The depressed nasal areas become the nasal pits and are separated by a broad mass of tissue —the *frontonasal* (frontal) *process*. As the pits deepen they separate in a sense the caudal portion of the frontonasal process into medial and lateral parts—the rudiments of the medial and lateral nasal processes. Indeed, the latter processes have their precursors in the low folds of meso-ectodermal tissue which isolate the nasal areas. During the latter part of the fourth week, probably a bit later, the median portion of the

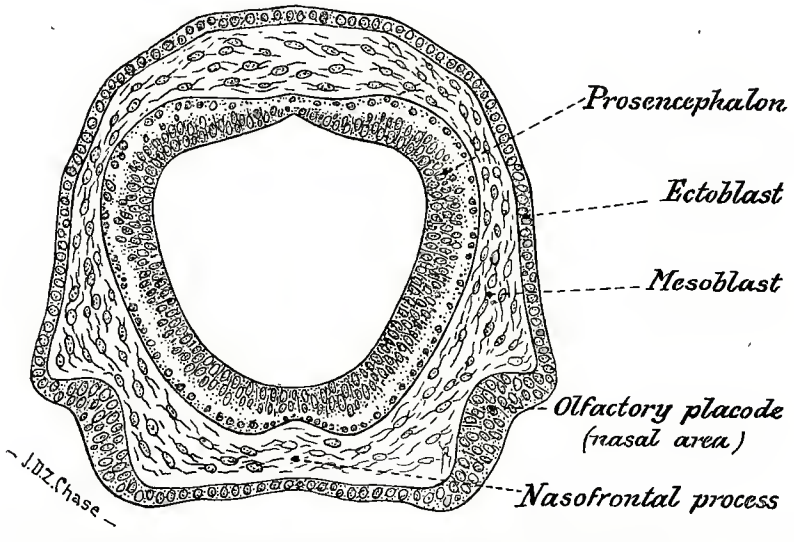

FIG. 1.—Section through the head of a human embryo aged approximately 3 weeks. The section shows the olfactory placodes sharply delimited from the surrounding head ectoblast. Redrawn from Kollmann.

frontonasal process undergoes further differentiation into a mesial or unpaired part and two lateral or paired parts. The latter are more specifically the *medial nasal processes* or the globular processes of His, and they form the immediate medial boundaries of the nasal pits. The lateral portions of the frontonasal projection grow caudally and form the *lateral nasal processes*—the immediate lateral boundaries of the nasal pits or the primitive (primary) lateral nasal walls.

At this stage of development the *maxillary processes* of the first or mandibular arches grow ventrally and medially and abut, later fuse with the medial nasal processes. The fusion takes place from within outward, *i.e.*, from the depth toward the surface, and closes in the superior bound-

ary of the primitive oral cavity and at the same time early shuts off the cleft of communication between the nasal pits and the oral cavity. The coalescence of the maxillary processes with the medial nasal processes forms the primitive or primary inferior boundary of the nasal pits. Subsequently, however, the extensions of the lateral nasal processes medially and ventrally above the maxillary processes meet and fuse with the medial nasal processes to form the immediate definitive inferior boundary of the

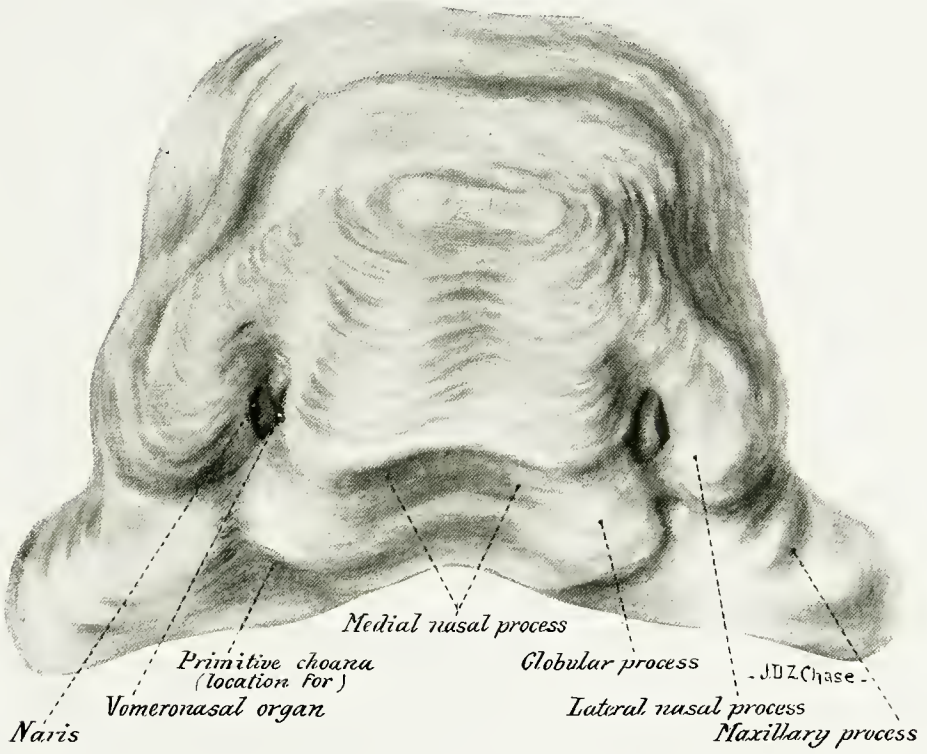

FIG. 2.—Drawing of a reconstruction by the author of the face region of a human embryo aged 35 days, illustrating the several embryologic processes and their coalescence in the formation of the early nasal fossæ. × 39.

nasal pits. Fusion takes place also laterally between the maxillary and the lateral nasal processes in the obliteration of the naso-optic furrow (Fig. 2).

For a brief time the lines of fusion of the maxillary and the lateral nasal processes with the medial nasal processes are represented by strands of ectodermal tissue. These ectodermal fusion-lines or plates soon disappear ventrally and cranially and are replaced by indifferent mesenchyme; that is, the mesenchymal tissue of the maxillary and lateral nasal processes becomes continuous with that of the medial nasal processes.

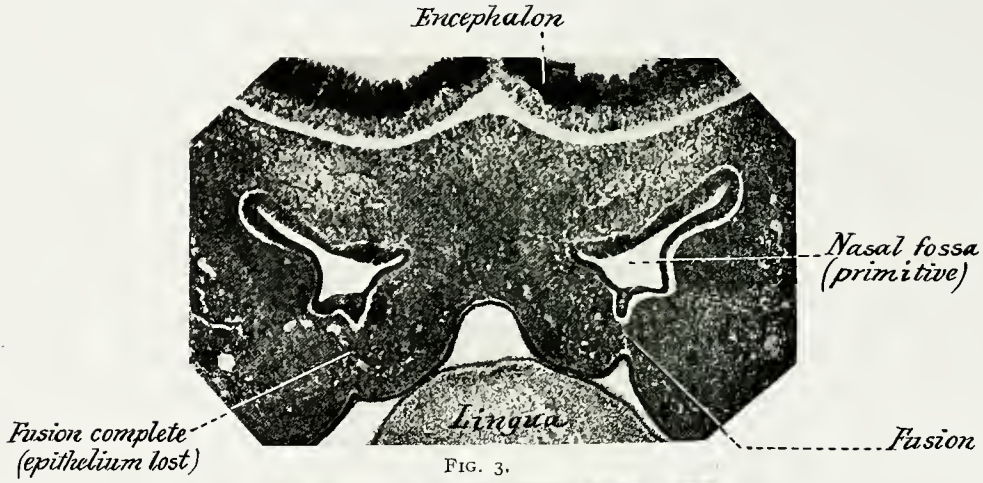

FIG. 3.

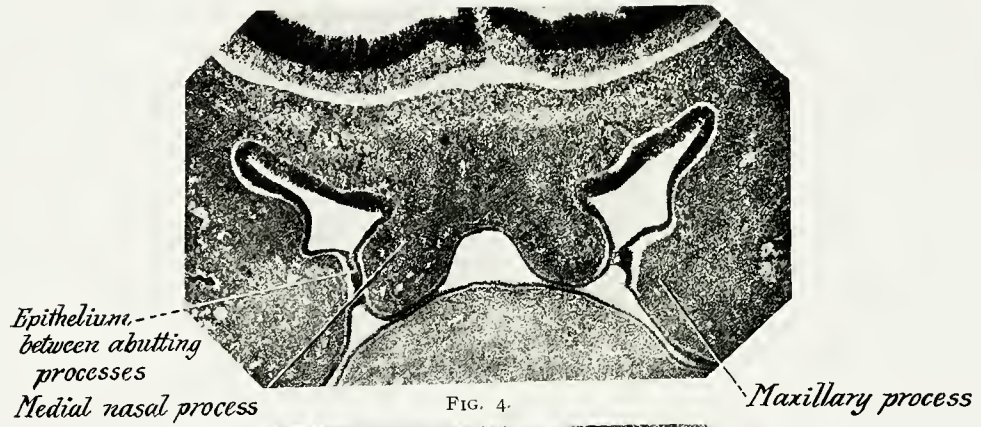

FIG. 4.

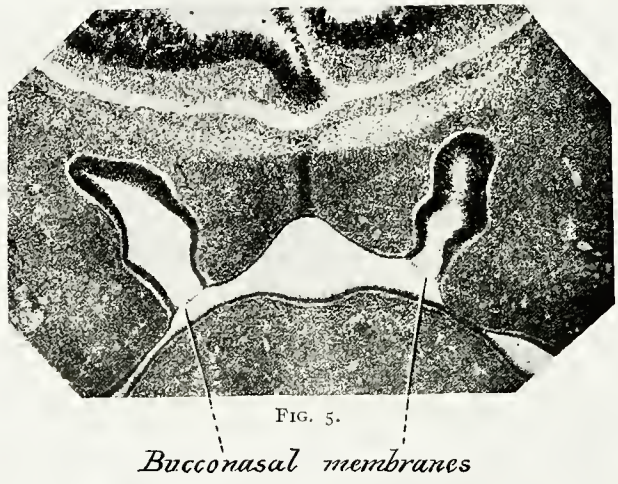

FIG. 5.

FIGS. 3–5.—Photomicrographs of frontal sections of the head of an embryo aged 35 days. (Human embryo, No. 26, Cornell University series, slides 19 and 20.)

Fusion in this manner becomes permanent and absolute. Persistent epithelial-cell masses may later in extrauterine life, or before, give rise to epithelial pearls and cysts. Farther dorsally the ectodermal tissue does not wholly disappear for some time, strands remaining between the abutting processes. In these positions the primitive choanæ (primitive posterior nares) become established ultimately and the ectoderm of the nasal pits then becomes continuous with that of the oral cavity (Figs. 3, 4, 5 and 6).

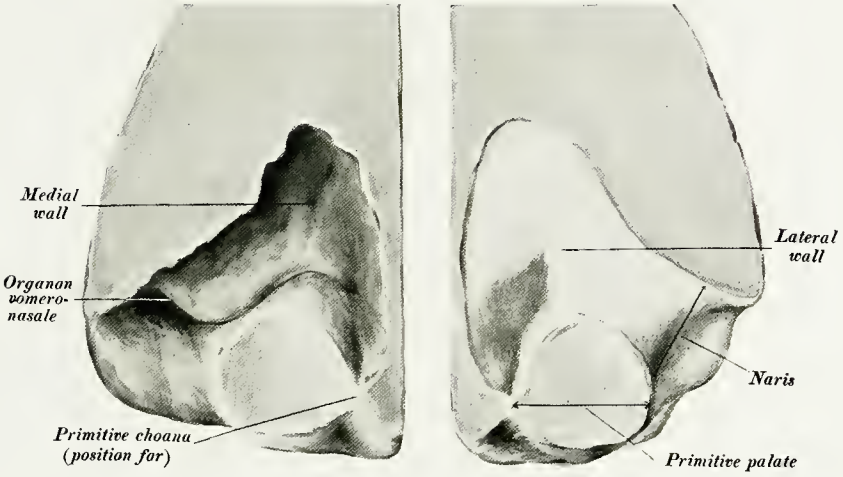

FIG. 6.—Drawing of a reconstruction by the author of the left nasal fossa of a human embryo aged 35 days (Embryo No. 6, see Fig. 2). Especially note the simple lateral nasal wall at this period and the blind termination of the nasal fossa dorsally. × 72.

THE PRIMITIVE (PRIMARY) NASAL FOSSÆ

Thirty-five-day embryos show that the nasal pits have deepened sufficiently to partake of the nature of cleft-like fossæ. The olfactory organ is now represented by two blindly-ending epithelial pouches lying in the mesenchymal tissue just above the oral cavity. The fossæ communicate freely with the exterior by means of the nares (anterior nares), but in the absence of choanæ (posterior nares) end blindly at their dorsal and inferior termination. They are widely separated at this time by the thick frontonasal process. Reference to a 35-day embryo indicates the simplicity of the lateral nasal wall at this time—an even and unbroken surface presents for study. The medial or septal wall, on the

Particularly note the manner of fusion of the embryonic processes in the obliteration of the communication between the nasal fossæ and the oral cavity. In Fig. 5 on both sides the two layers of epithelium, oral and nasal, have become attenuated and thinned out to represent single layers of cells—the bucconasal membranes. The latter ultimately rupture to establish the primitive choanæ. × 35.

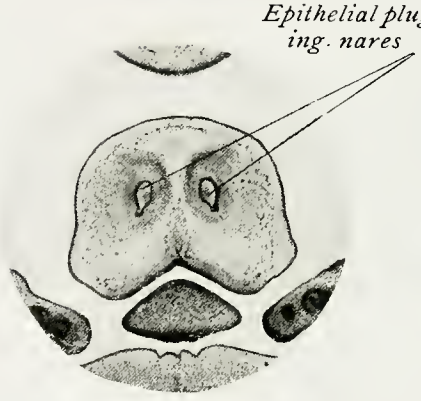

FIG. 7.

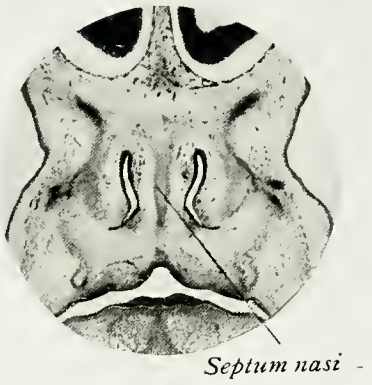

FIG. 8.

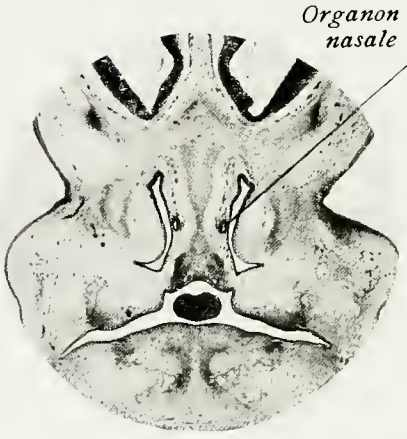

FIG. 9.

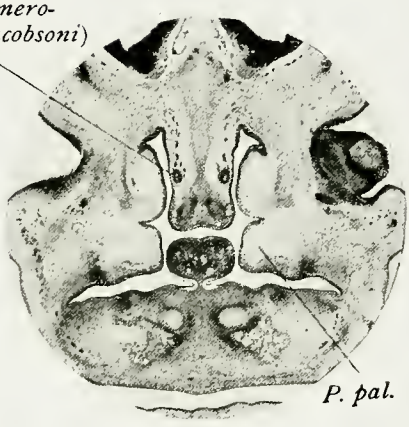

FIG. 10.

FIG. 11.

FIG. 12.

FIGS. 7–12.—Photomicrographs of frontal sections of the head of an embryo aged 43 days. (Human embryo, No. 3, Cornell University series, sections 406, 380, 365, 360, 350, 325.)

contrary, is more complicated owing to the rudiment of the vomeronasal organ of Jacobson, which is indicated by a slight groove overhung by a mucosal fold (Fig. 6).

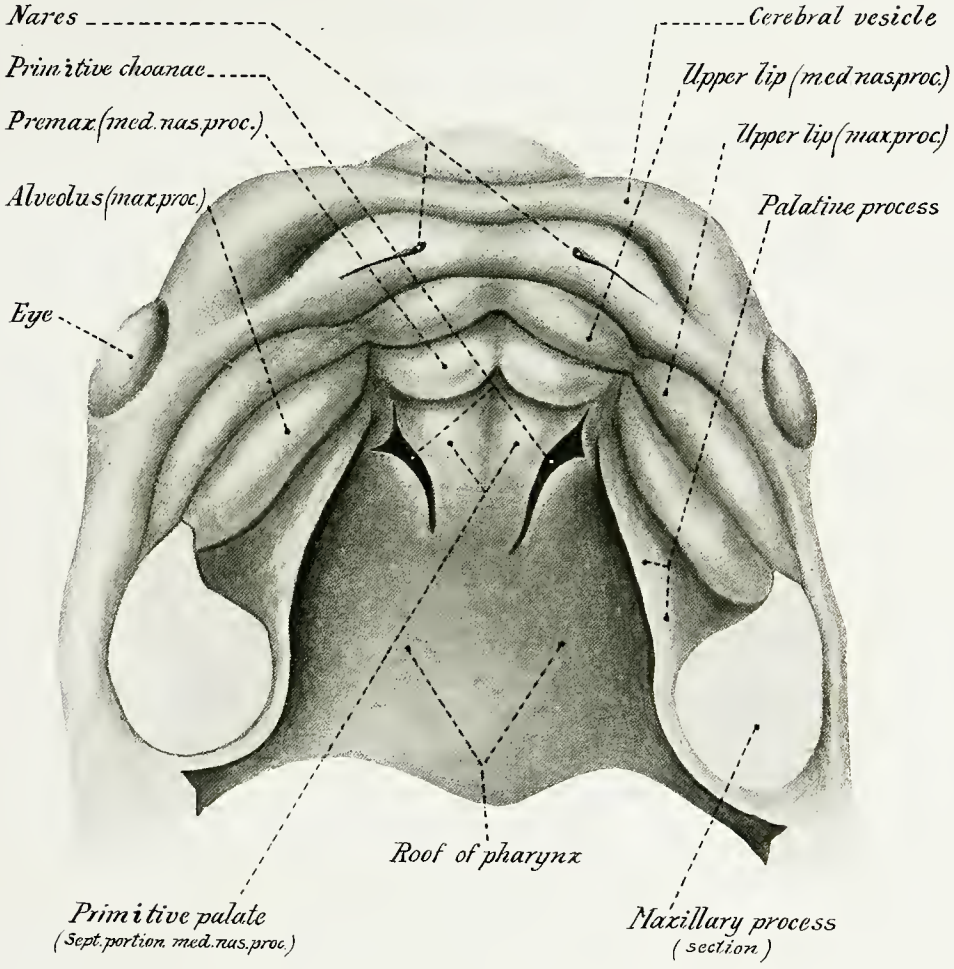

FIG. 13.—Reconstruction of the face and palate regions of a human embryo at the beginning of the 2d month. Especially note the primitive palate and the early palatine processes which are beginning to grow toward the mid-line in anticipation of the definitive palate. (Redrawn from Keith after Kollmann.)

The Bucconasal Membranes and the Primitive Choanæ or Posterior Nares.—The dorsal growth or extension of the blind, pouch-like primitive nasal fossæ meets the ectoderm of the oral fossa. One now finds in

Note the plugging of the nares in photograph 7; moreover, that the nasal conchæ as illustrated in photographs 8–11 have no cartilage in them at this age. The mesenchymal tissue is, however, undergoing condensation in anticipation of cartilage in the region of the nasal septum and the lateral nasal walls. Note also the relation of the tongue to the palatal processes. × 12.3.

P. pal. = processus palatinus; Eth. fold = ethmoidal fold; Max. fold = maxillary fold.

these positions the bucconasal membranes composed of two layers of abutting epithelium (nasal and oral), separating the dorsal portion of the primitive nasal fossæ from the oral cavity (10 mm. embryos). In 35- to 38-day embryos the membranes are so attenuated that rupture usually ensues and the primitive choanæ (primitive posterior nares) are thus established, and with them communication between the nasal fossæ and the oral cavity. Lack of rupture of the bucconasal membranes leads to atresia of the choanæ, a condition occasionally observed in fetuses and in the newborn. Secondary blocking of previously patent choanal apertures due to epithelial overgrowth has been observed by the writer.

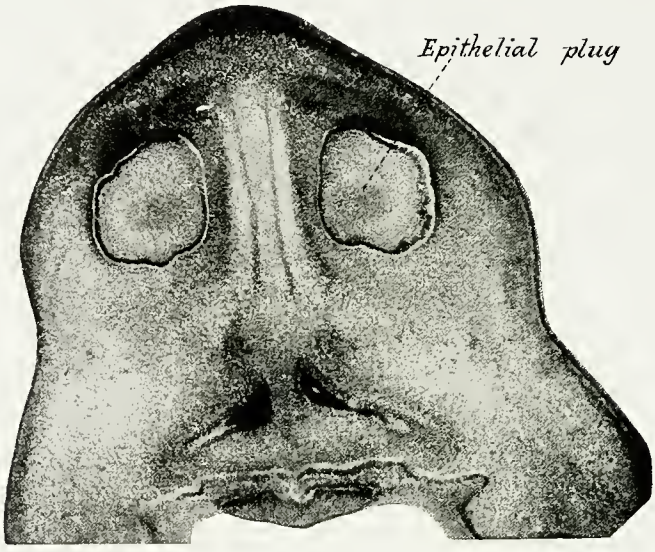

FIG. 14.—Photomicrograph of a frontal section through the ventral portion of the nose of a human embryo aged 49 days. (Embryo No. 28, Cornell University series, slide 40.)
Especially note the epithelial plugs occluding the nares. × 19.

The primitive choanæ do not correspond in position to the definitive choanæ. The latter are placed farther dorsad and are established in the third month when the definitive palate is completed. The primitive choanæ are located well in advance of the buccal pituitary outgrowth in the roof of the mouth and are separated by the primitive or primary nasal septum (Figs. 5, 6 and 13).

The Nares (anterior nares).—When first formed the nares communicate freely with the exterior and their embryological anatomy is essentially that of the early nasal pits. The luminæ of previously patent nares in very many instances become temporarily obstructed by a marked proliferation of the epithelial cells. In some cases the closure is absolute, in

others deviating passageways exist. As pointed out by the writer in an earlier publication[1] the plugging is rather common from the fortieth to the sixtieth day of embryonic life. Later there is a solution of the closure by degeneration of the central masses and by an active shedding, and the nares are again open to the exterior. As evidence of shedding, one often finds shreds of epithelial masses protruding from the nares. Lack of solution of the closure produced by these epithelial plugs leads to an atresia of the nares. The masses may become organized, as is attested by the membranous and bony atresias and stenoses of the nares that are encountered (Fig. 14).

The Primitive Palate.—Fusion of the maxillary and lateral nasal processes with the medial nasal processes and the rupture of the bucconasal

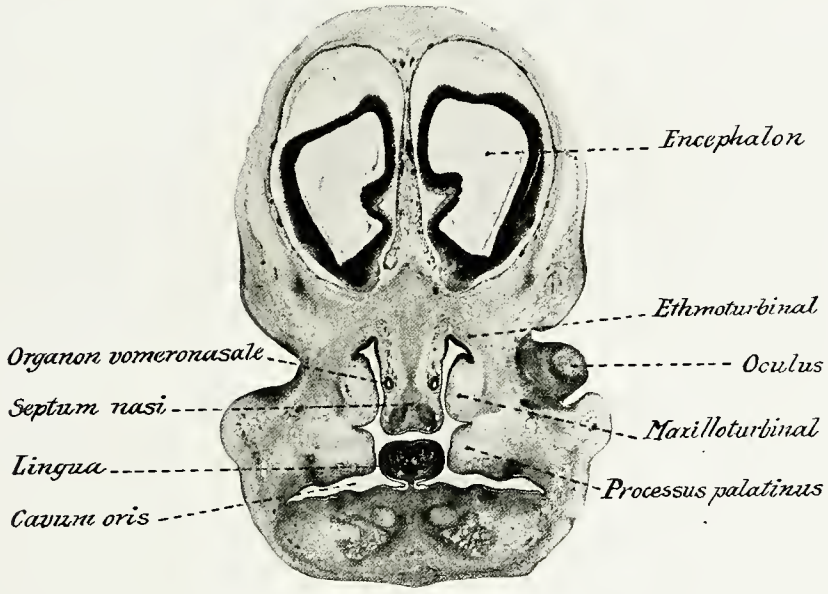

FIG. 15.—Photograph of a frontal section through the head of an embryo aged 43 days. (Embryo No. 3.) × 15.

membranes in the establishment of the primitive choanæ or posterior nares delimit for the first time the primitive palate. The latter presents a facial and an oral portion, the former giving rise to the upper lip and the latter to the premaxillary plate. It has been established that the mesoderm of both the facial and the oral portions is a derivative from the maxillary and medial nasal processes, the lateral nasal process participating only at the caudal border of the naris (anterior naris), *e.g.*, the middle portion of the primitive palate is derived from the medial nasal

[1]Jour. Morph., Vol. 21, 1910.

process, the dorsolateral portion from the maxillary process, and the ventrolateral portion from the lateral nasal process (Figs. 6 and 13).

The Definitive Palate.—The first step in the production of the definite palate is the appearance of the palatal ridges. These are wedge-shaped processes which grow caudally and somewhat medially from the medial sides of the maxillary processes. The palatal processes appear from the forty-fifth to the forty-eighth day of embryonic life. They at first hang almost vertically toward the mouth cavity, on either side of

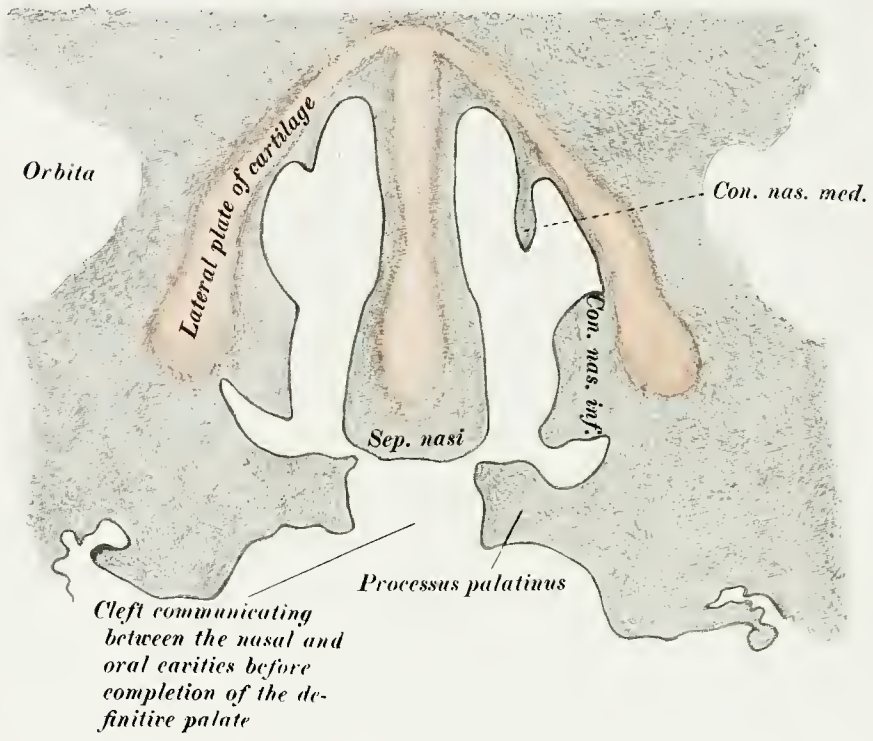

FIG. 16.—Frontal section through the nasal fossæ of a human embryo aged 49 days. (Embryo 12 H.) Especially note that the palatal processes have assumed a horizontal direction in anticipation of the completion of the definitive palate. Moreover, note that the nasal conchæ do not have cartilage in them at this time. × 28.

the tongue, and extend from the line of union between the medial nasal and the maxillary processes where they are continuous with the primitive palate, dorsad to the wall of the pharynx where they are continuous with the palato-pharyngeal folds. The palatal processes limit the lateral walls of the cavum nasi caudally (Fig. 8).

For a relatively brief time the tongue is between the palatal processes, the latter extending below the level of the dorsum of the tongue. Subse-

quently the tongue seemingly sinks and comes to occupy a lower position in the mouth cavity. Concomitant with this change of the tongue the palatal processes become passively rather than mechanically rotated, due to an unequal growth, from an almost vertical and sagittal plane to a horizontal plane and subsequently meet in the median sagittal plane over the tongue—fusion taking place from before backward along the opposed edges. Nests of epithelial cells may persist between the fused elements giving rise later to epithelial pearls or even to cysts. The dorsal parts of the folds maintain their original direction. Subsequently bony plates extend into the membranous palatal processes to form the greater

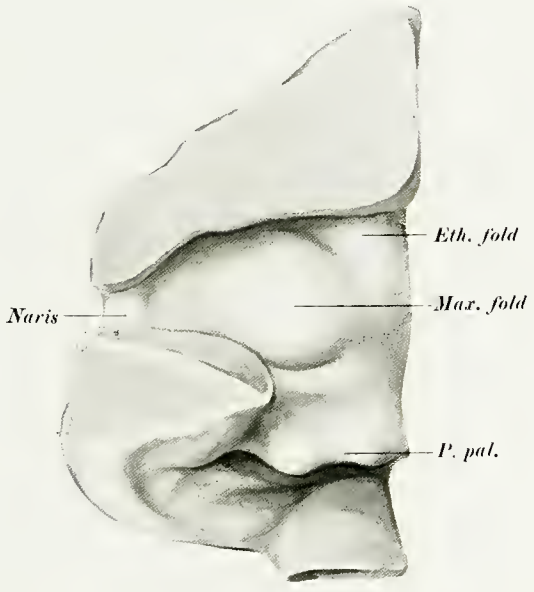

FIG. 17.—Drawing of a reconstruction of the lateral wall of the nasal fossa of an embryo aged 43 days. (Human embryo No. 3, Cornell University series, section 300–420 inclusive.) Particularly note that the palatal process (P. pal.) hangs in the sagittal plane at this time. The maxillary fold (Max. fold), the rudiment of the inferior nasal concha, occupies the greater portion of the lateral nasal wall while the ethmoidal fold (Eth. fold), the rudiment or anlage of the ethmoidal nasal conchæ, is relatively inconspicuous. × 24. (*After J. P. S.*)

portion of the hard palate. Dorsally these plates are wanting and muscular tissue extends into the processes, giving origin to the soft palate and to the uvula. In the formation of the definitive hard palate a substantial portion of the primitive buccal cavity is isolated and made part of the nasal cavity (Figs. 15, 16, 17, 18 and 19).

As was previously pointed out, the mesial nasal processes unite superficially to form the central part of the upper lip and philtrum and conjointly extend dorsad in the roof of the stomodeum to form the inter-

maxillary process (the greater portion of the primitive palate, *vide supra*). The intermaxillary process projects farthest dorsad in the median plane and by its lateral borders abuts with the lateral nasal processes ventrally and with the maxillary processes farther dorsally. At the dorsal ends of the planes of contact fusion is imperfect, leading to the formation of the incisive foramina (anterior palatine canals). The latter transmit (*a*) nerves and vessels which course between the mucosæ of the oral and nasal cavities and (*b*) the nasopalatine canals (canals of Stenson) which early connect the nasal and oral cavities, but in later life generally become oblit-

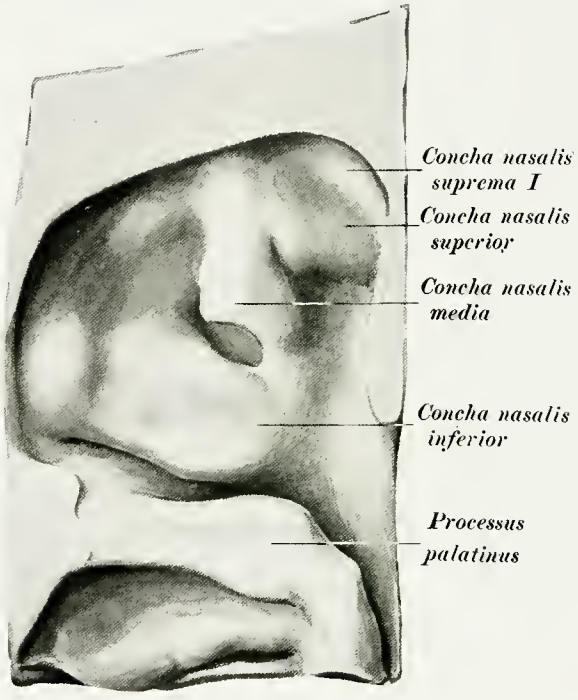

FIG. 18.—Drawing of a reconstruction of the lateral wall of the nasal fossa of an embryo aged 49 days. (Human embryo No. 28, Cornell University series, slides 40–51 inclusive.)

Especially note that the palatal process has now assumed a horizontal position in anticipation of the completion of the palate. Moreover, note that the ethmoidal fold has enlarged and become differentiated into a number of ethmoidal conchæ. × 26. (*After J. P. S.*)

erated, at least at their oral extremities (see page 76). Little of the primitive palate is so located as to participate in forming the adult palate proper.

The Definitive Choanæ (posterior nares).—Coincident with the growth of the facial region and the formation of the palatal processes the primitive or primary choanæ become elongated and form slit-like passageways between the nasal and oral cavities (Fig. 13). The continued growth and the ultimate fusion from before backward in the mid-sagittal

plane of the palatal processes in the formation of the secondary palate, and the buccal and pharyngeal extensions of the primary nasal septum, force the primitive or primary choanæ to undergo a steady dorsal migration until communication with the cephalic and ventral termination of the pharynx is established. This connection locates the definitive choanæ

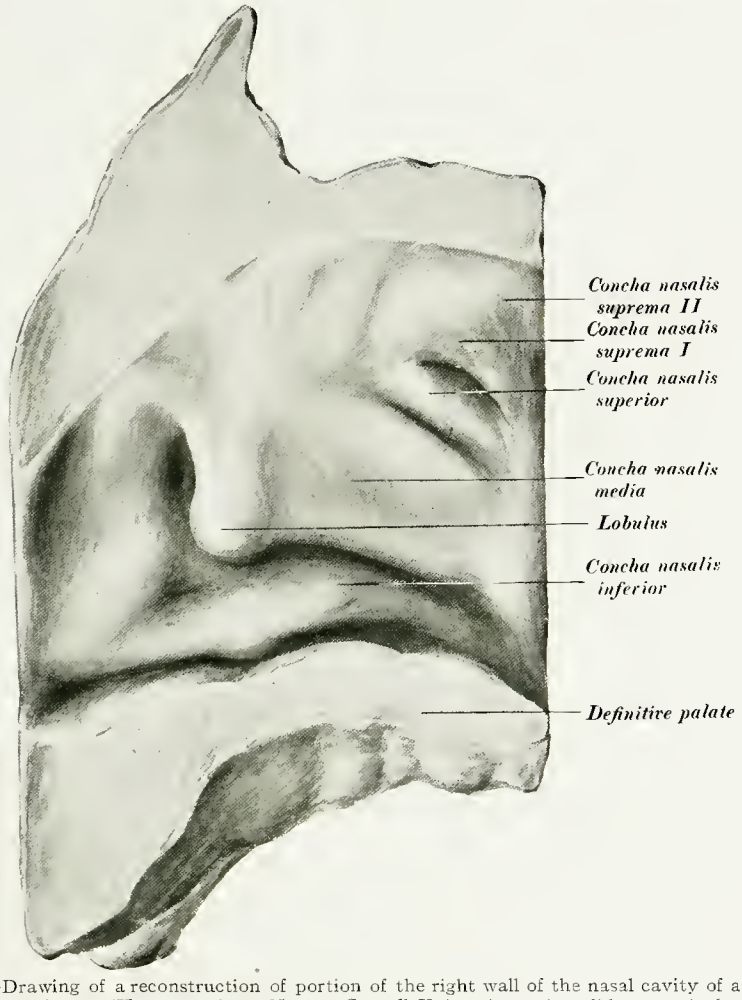

FIG. 19.—Drawing of a reconstruction of portion of the right wall of the nasal cavity of an embryo aged 105 days. (Human embryo No. 43, Cornell University series, slides 1–90 inclusive.)

Note that the definitive palate is now completed and that the choana has assumed its final position. The ethmoidal field has differentiated into four nasal conchæ. Especially note the marked lobule in the region of the knee of the concha nasalis media. × 9.5. (*After J. P. S.*)

or posterior nares. As the primary choanæ migrate dorsally, due to the fusing of the palatal processes, the nasal septum fuses with the mid-palatal ridge to divide the nasal cavity into the right and left nasal fossæ. Here, too, the division and fusion take place from before backward.

The Primary Nasal Septum (the septum nasi primum).—The mesial nasal processes—the symmetrical mesial and caudal extensions of the frontonasal process—fuse together and form the middle third of the upper lip, the intermaxillary process, and the primary nasal septum between the primitive (primary) nasal fossæ. Moreover, when the primitive nasal fossæ establish communication with the roof of the buccal cavity by the formation of the primitive choanæ, it is the primary nasal septum that intervenes between these apertures as a wide plate in the roof of the mouth.

The Secondary Nasal Septum (the septum nasi secundum).—During the latter part of the second month of fetal life after the primitive choanæ are formed, the primary nasal septum begins to grow buccalward and pharyngealward until the aperture of the buccal pituitary outgrowth is

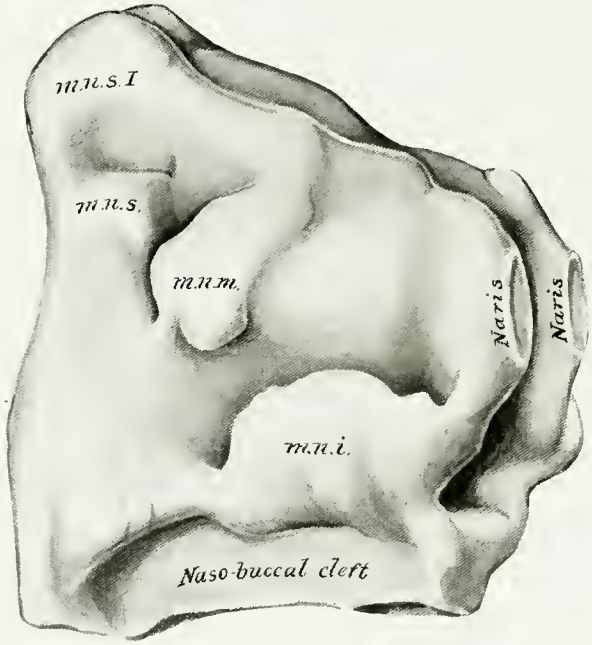

FIG. 20.—Model of the nasal cavity of a 49-day human embryo. Particularly note the connection (nasobuccal cleft) between the nasal fossæ and the mouth cavity.

M. N. S. I. = Meatus nasi supremus I; M. N. S. = Meatus nasi superior; M. N. M. = Meatus nasi medius; M. N. I. = Meatus nasi inferior.

included in its dorsocranial border. Coincidently, the nasal fossæ are elongated in the ventrodorsal plane, the definitive palate is completed, and the definitive choanæ are established in the region of the naso-pharynx (end of third month). Moreover, the secondary nasal septum has extended sufficiently buccalward to fuse with the mid-palatal ridge, which it does from before backward, in the division of the general nasal cavity into the definitive nasal fossæ.

The Definitive (Secondary) Nasal Fossæ

With the completion of the boundaries, that is, the medial and lateral walls, the roof and floor, and the choanal apertures, the nasal fossæ are not limited to their primitive site, but have incorporated a goodly portion of the buccal cavity on the nasal side of the hard palate and in a sense they pass into a secondary developmental stage. It is, therefore, suitable to

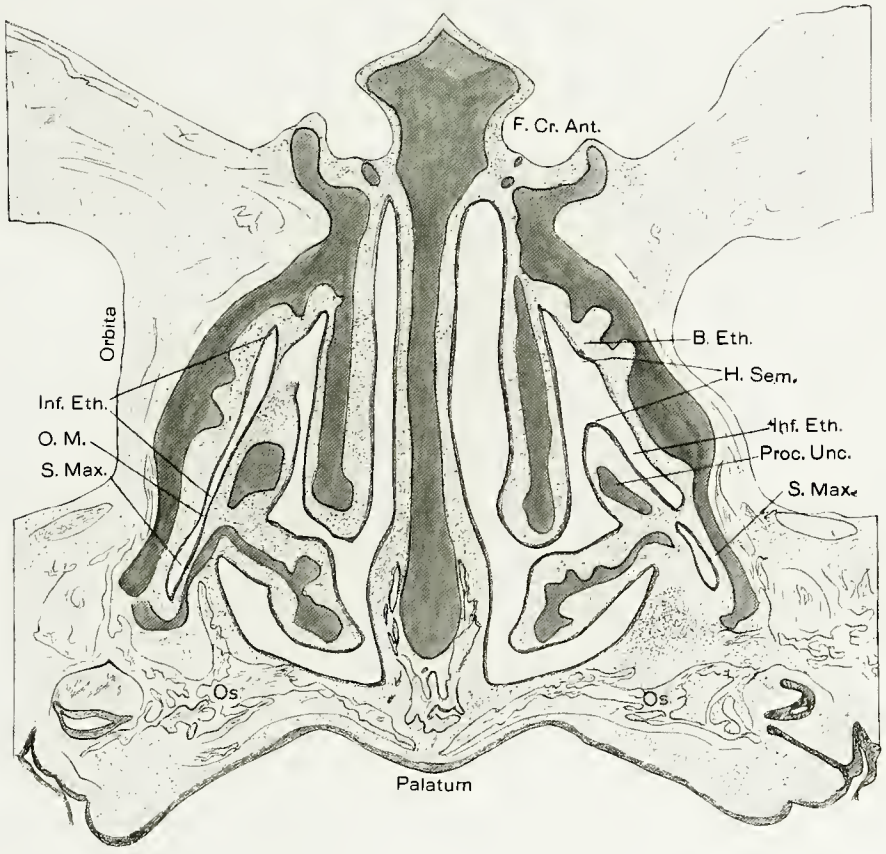

FIG. 21.—Frontal section of the nose of a human embryo aged 120 days. On one side the section is through the region of the ostium maxillare and on the other dorsal to it. Note the fusion on the left side between the processus uncinatus and one or more frontal conchæ. This causes the infundibulum ethmoidale to end blindly ventrocephalically. Farther dorsad as illustrated on the right side the infundibulum ethmoidale is of course in wide communication with the meatus nasi medius via the hiatus semilunaris. × 10.

F. cr. ant. = Fossa cranii anterior; Inf. eth. = Infundibulum ethmoidale; O. m. = Ostium maxillare; S. max. = Sinus maxillaris; B. eth. = Bulla ethmoidalis; H. sem. = Hiatus semilunaris; Proc. unc. = Processus uncinatus; Os = maxilla undergoing ossification.

speak of the primitive nasal fossæ and the incorporated portion of the buccal cavity as conjointly forming the definitive or secondary nasal fossæ.

It is during the secondary phase of development that the nasal bound-

aries continue their chondrification and ossification, that the elements entering into the boundaries attain definition. Moreover, the previously simple lateral nasal wall undergoes profound metamorphosis in the formation of the appendages which ultimately characterize its surface; the paranasal sinuses begin to take form and position, while the septal wall, on the contrary, becomes relatively more simple as its definitive form is reached.

It must, however, be understood that there is no sharp border line between the *primitive* and *definitive* growth periods of the nasal fossæ; rather that growth processes begun in the primitive period are continued and carried to fruition in the secondary period. In a sense, during the primitive stage of development the foundation and superstructure of the nose are formed and in the subsequent period the interior and exterior are molded and modeled in the formation of many secondary, yet complex and important structures.

The Lateral Nasal Wall

The lateral wall of the nasal fossa of a 35-day embryo gives no evidence whatsoever of its later complexity. Indeed, the medial or septal wall is more complicated at this stage of development owing to the vomeronasal organ which is a prominent structure in the early embryo. There is an inherent tendency for the nasal cavity early and rapidly to increase its surface area. Even before the first appearance of the palatal processes as limiting shelves for the nasal fossæ caudally, the lateral walls of the fossæ have begun in a simple manner the complex configuration which ultimately characterizes them. The complexity in the anatomy of the lateral wall is due to the development of the major nasal conchæ (turbinates), the minor (accessory) nasal conchæ, the major nasal meatuses, the secondary nasal meatuses, and the paranasal (accessory) chambers.

The portion of the inferior nasal meatus that lies dorsal to the incisive canal, together with the space immediately behind the dorsal extremities of the ethmoidal conchæ as far back as the ostium of the auditive tube (Eustachian tube), is derived from the primitive buccal cavity of the fetus, having become isolated by the formation of the definitive palate. The dorsal extension of some of the nasal conchæ toward the choana beyond the confines of the primary nasal fossa is purely secondary.

(A) **The Major Nasal Conchæ** (endoturbinals) and **Meatuses.**—The conchal or turbinal apparatus of the human nose is much reduced, and its development takes place entirely in the region of the sensory epithelium, *e.g.*, in the primitive nasal cavities. The conchæ arise on both the lateral and medial walls of the nasal fossa: The agger nasi (nasoturbinal)

and the concha nasalis inferior (maxilloturbinal) arise from the lateral wall, and the conchæ of the ethmoid region (ethmoturbinals) arise in part (J. P. Schaeffer)[1] or wholly (Peter)[2] from the median wall. By a process of unequal growth the ethmoidal conchæ are transferred wholly to the lateral nasal wall. It is, of course, essential that appropriately aged embryos are studied for the initial stage. The transference to the lateral wall occurs at an early time and this may mislead the investigator.

FIG. 22. FIG. 23. FIG. 24. FIG. 25.

FIGS. 22–25.—Reconstructions of portions of the lateral nasal wall in the frontal plane and at various levels. (Human embryo, aged approximately 125 days.) Fig. 22 represents the nasal wall farthest ventrad and Fig. 25 farthest dorsad.

Ie. = Infundibulum ethmoidale; Mnm. = Meatus nasi medius; Cnm. = Concha nasalis media; Cni. = Concha nasalis inferior; Sn. = Septum nasi; Cns. = Concha nasalis superior; Be. = Bulla ethmoidalis; Hs. = Hiatus semilunaris; Om. = Ostium maxillare; Pu. = Processus uncinatus; S. max. = Sinus maxillaris; Mni. = Meatus nasi inferior.

The mechanism by which the nasal conchæ and meatuses are initially formed is variously interpreted. At the outset it may be definitely stated that in the conchæ of the human nose the skeleton is not the primary structure as is so frequently given. Cartilage does not grow into the primitive (primary) conchæ, but develops or arises within previously

[1] Schaeffer: The Lateral Wall of the Cavum Nasi in Man with Especial Reference to the Various Developmental Stages, Jour. of Morph., Vol. 21, 1910.

[2] Peter: Die Entwicklung der Nasenmuscheln bei Mensch und Säugetiern, Archiv f. mikroskop. Anatom., Bd. 79, 1912.

established conchal rudiments or anlages composed of epithelium and subjacent indifferent mesenchyme. In other words, the conchæ or turbinates are not primarily produced by inpushings of the nasal wall due to cartilaginous strands or bars. Indeed, the initial conchæ are present before the precartilage stage of the mesenchyme (Figs. 8 to 12).

The Inferior Nasal Concha (concha nasalis inferior) and *the Inferior and Middle Nasal Meatuses* (meatus nasi inferior et medius).—After a study of the blastemal period and early development of these structures, the writer is led to believe that the first change in the lateral nasal wall from a more or less even and unbroken surface is the production of two shallow grooves, one inferior and the other superior to the position of the

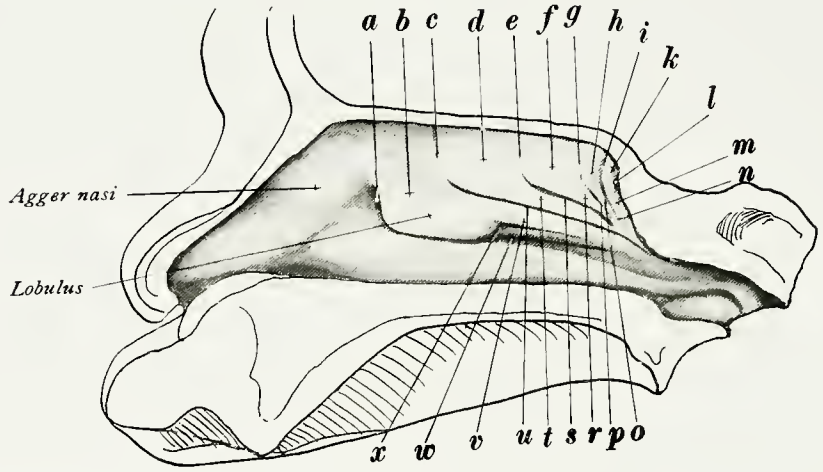

FIG. 26.—The lateral nasal wall of a term fetus. Note particularly the large number of ethmoidal conchæ that are occasionally differentiated. × 1.5. This and the following figures, 27–34, are after Schaeffer, Journal of Morphology, Vol. 21, No. 4.

a, *c*, *e*, *g*, *i* = ascending rami of the ethmoidal meatuses; *w*, *u*, *s*, *p*, *n* = descending rami of the ethmoidal meatuses; *b*, *d*, *f*, *h*, *k* = ascending crura of the ethmoidal conchæ; *v*, *t*, *r*, *o*, *m* = descending crura of the ethmoidal conchæ; *l* = sinus sphenoidalis; *x* = incisura retrolobularis.

primitive concha nasalis inferior (38- to 40-day embryos). These shallow grooves, the rudiments of the meatus nasi inferior and medius, throw at once into slight relief the greater portion of the lateral nasal wall and establish the initial stage of the concha nasalis inferior (maxilloturbinal). The indifferent mesenchymal tissue contained within this primitive fold simultaneously undergoes proliferation and aids in making the fold more prominent. The mucous membrane over the fold is but slightly thickened at this time. The writer is not in accord with those who argue that the formation of a well-developed maxillary fold is wholly due to the formation and deepening of the bordering furrows. The formation of the shallow furrows is doubtless the primitive step in conchal formation.

However, the proliferation of the indifferent mesenchyme contained in the fold aids materially in causing the primitive concha inferior to bulge into

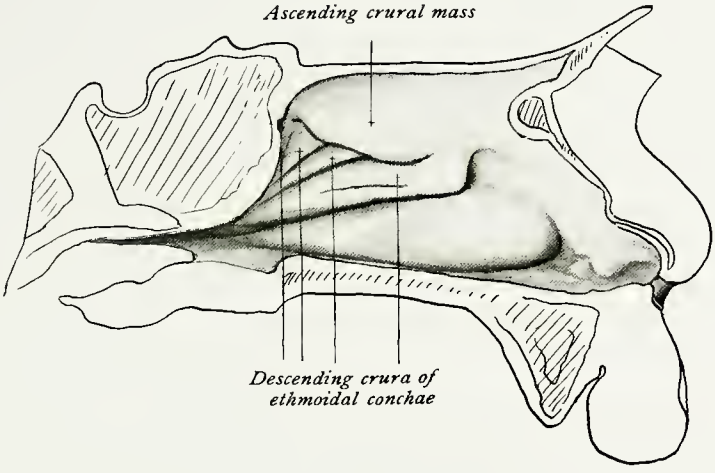

FIG. 27.—The lateral nasal wall of a term fetus.

the lumen of the nasal fossa and the bordering furrows to become passively deeper (Fig. 17).

The Ethmoidal Conchæ (conchæ ethmoidales) and *the Superior and First, Second and Third Supreme Nasal Meatuses* (meatus nasi superior et

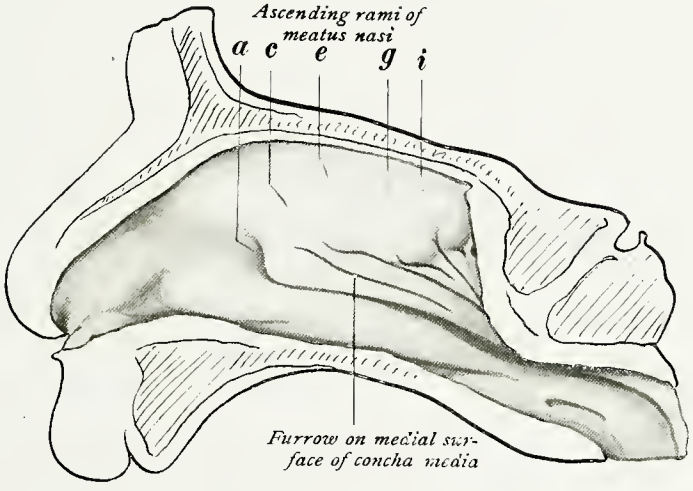

FIG. 28.—The lateral nasal wall of a term fetus.

supremæ I, II, III).—The ethmoidal fold (rudiment of the ethmoidal conchæ) appears next in the extreme dorsal and superior portion of the

nasal fossa in the angle formed by the lateral wall and nasal septum. Since the primitive concha inferior (maxillary fold) takes up the greater portion of the lateral nasal wall at this time, there is little room for the primitive ethmoidal fold. In a former study the author[1] concluded that the ethmoidal fold arose both from the septal and lateral walls. Peter,[2] on the contrary, believes that it arises in whole from the septal wall. With further and unequal growth of the nasal fossa in the dorso-superior direction, the ethmoidal fold passively migrates from the septal to the lateral nasal wall. The mucous membrane over the ethmoidal fold is, as a rule,

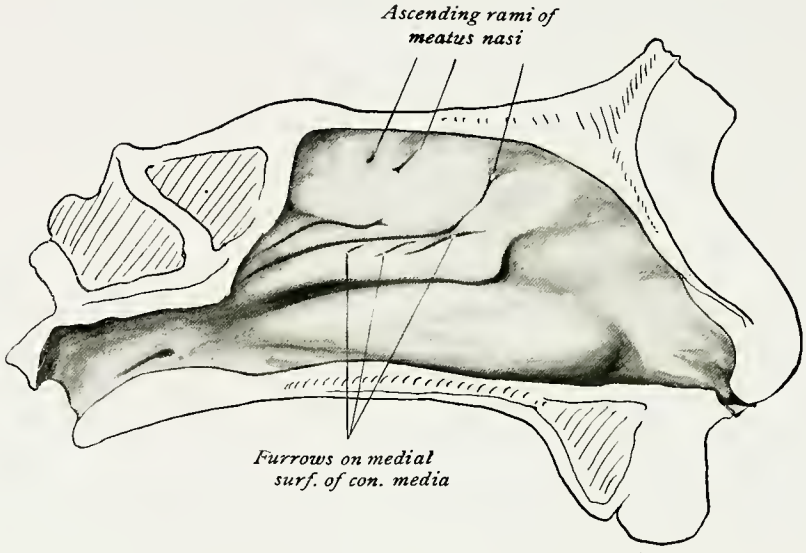

FIG. 29.—The lateral nasal wall of a term fetus. Particularly note the multiple furrows on the medial surface of the concha nasalis media.

thickened. Gradually, in place of the single ethmoidal fold, there are established rudiments of the individual ethmoidal conchæ or turbinates. The development of these conchæ proceeds from the most caudal to the most cephalic. One sees two ethmoidal conchæ in embryos aged approximately 48 days, three conchæ in embryos aged 95 to 100 days. In fetuses from the seventh month to term, one finds from three to five ethmoidal conchæ with a corresponding number of intervening meatuses. After birth the ethmoidal conchæ are usually reduced in number by a coalescence of the uppermost and less developed members with a resultant obliteration of the intervening meatuses. When the usual two or three ethmoidal conchæ are found in the adult, it is difficult to decide whether coalescence

[1] Loc. cit.
[2] Loc. cit.

of parts (regression) or lessened differentiation (progression) was the determining factor. In the adult one rarely finds more than three ethmoidal conchæ. Therefore, numerical reduction must be a factor in some instances (Figs. 26 and 146).

Doubtless the personal equation is an important factor in the divergent findings reported as to the number of fetal ethmoidal conchæ that are differentiated. In many cases the more cephalic folds are extremely rudimentary and are usually overlooked or considered too small to be counted as ethmoidal conchæ. The conchæ supremæ II and III, when differentiated, as a rule early lose their identity by fusion, and in infancy and adult life three ethmoidal conchæ must be considered the typical number rather than two as usually given. An examination by the author

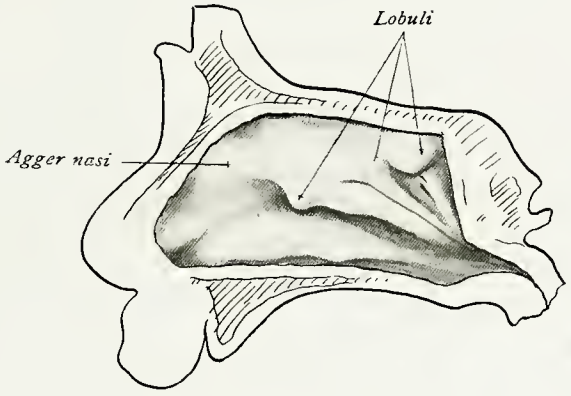

FIG. 30.—The lateral nasal wall of a 210-day fetus. Note especially the lobuli on the ethmoidal conchæ.

of 264 infant and adult specimens showed 160 with three ethmoidal conchæ, 98 with two ethmoidal conchæ, 4 with four ethmoidal conchæ, and 2 with one ethmoidal concha. The ostium of the posterior ethmoidal cell which develops from the meatus nasi suprema I is a good and reliable point for orientation in determining the presence of a concha nasalis suprema I. The latter is present, according to the author's studies, in approximately 60 per cent. of the cases, and in 75 per cent. of them a posterior ethmoidal cell develops from the corresponding meatus (Fig. 127). The latter anatomical fact needs explanation by those who argue that two ethmoidal conchæ represent the typical field; especially so when one recalls that the cellulæ ethmoidales develop from preformed nasal meatuses.

The group of ethmoidal conchæ and meatuses in a general way early possess knees, thus giving rise to ascending and descending crura. The

angular condition lessens as one passes from the middle concha and its corresponding meatus to the highest concha and meatus present. In

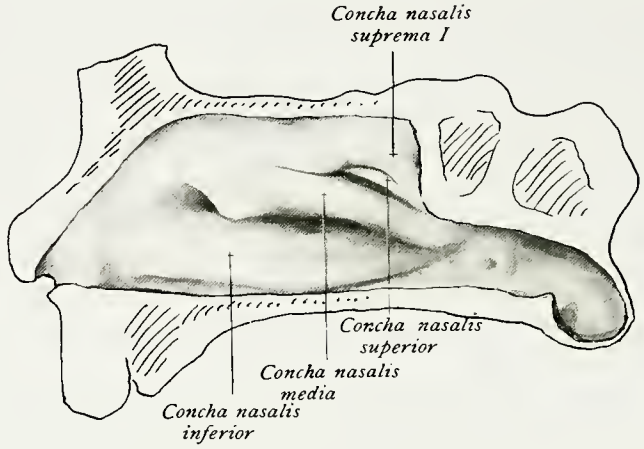

FIG. 31.—The lateral nasal wall of a 190-day fetus. Especially note the rudimentary character of the concha nasalis superior. × 2.3.

fact, the upper ethmoidal conchæ are represented mainly by the descending crura. Often the ascending crura are not at all differentiated, the

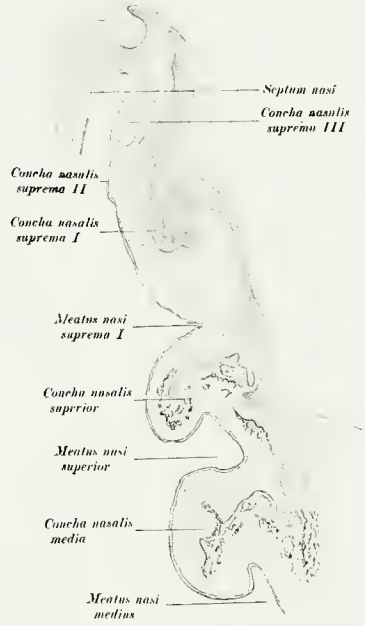

FIG. 32.—Drawing of a frontal section through the lateral wall of the nasal cavity in the region of the ethmoidal conchæ (fetus aged from 7–8 months, series B, slide 48). The concha nasalis inferior is not included in the section. × 8.

whole region being represented by a general undifferentiated crural mass (Fig. 27). Ascending and descending crura are, however, constant for the

concha nasalis media and the meatus nasi medius. The concha nasalis superior and its corresponding meatus also frequently persist in the adult as angular structures. Briefly stated, the integrity of the ethmoidal conchæ and meatuses is more or less dependent upon the descending or inferior crura, the middle concha and meatus excepted.

At the junction of the ascending and descending crura of the ethmoidal conchæ one commonly finds *overhanging lobule formations* (Figs.

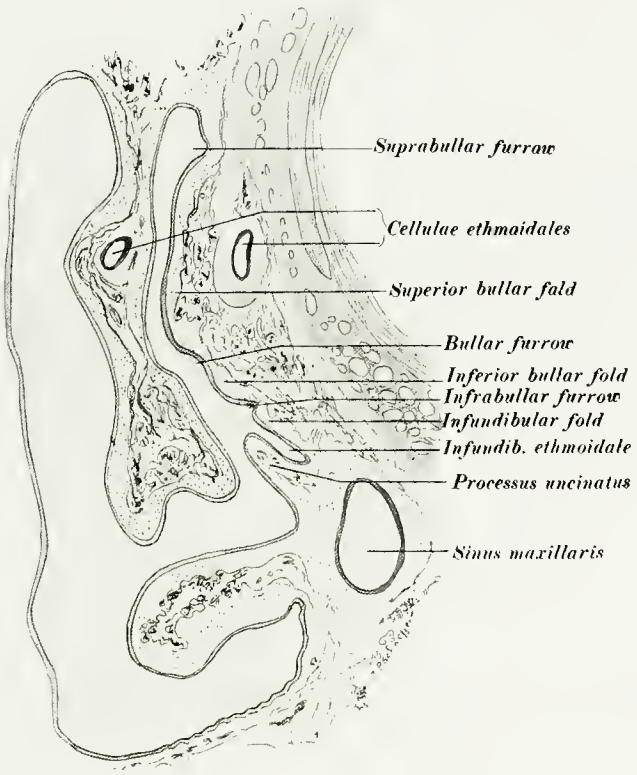

FIG. 33.—Drawing of a frontal section of the lateral wall of the left nasal fossa of a term fetus (series D, slide 5).

Note the individual folds comprising the bulla ethmoidalis. × 5.8.

19 and 30), the most marked and constant of which is found on the knee of the concha media. The latter lobule may be of such size as to lead to mechanical obstruction of the meatus nasi medius in the neighborhood. This lobule must not be mistaken for the later and very common distention of the middle concha due to an ingrowth of an infundibular or other anterior ethmoidal cell to become conchal in position. Mechanical obstruction of the meatus may likewise follow, depending upon the size

of the cell. *Secondary nodules* frequently form on each *primary lobule* (Fig. 30). The lobule and secondary nodules of the human ethmoidal conchæ (ethmoturbinals) are the homologues of the rather sharp ventral projections of the ethmoturbinals of mammals.

The concha nasalis media often presents a number of secondary furrows on its medial surface (Figs. 28 and 29). A single and deeply cut furrow often partially divides the concha into halves. Errors are frequently made in such instances in considering the portion inferior to the furrow as the concha media and the portion superior as the concha superior. Such an analysis would erroneously make of the furrow the meatus nasi superior. Zuckerkandl early made this error, but later corrected himself. A few recent publications continue to err in regards to the furrows found on the medial surface of the middle concha.

The Nasoturbinal (agger nasi) and the **Nasal Atrium** (atrium nasi, atrium meatus medii).—The nasoturbinal appears relatively late in man and is always extremely rudimentary as compared with the higher mammals, *e.g.*, rabbit, sheep, pig, ox, etc. It appears as a slight elevation cephalic to the concha inferior (maxilloturbinal) and ventral to the concha media (ethmoturbinal). It develops more or less parallel to the bridge of the nose. Infundibular cells (anterior ethmoidal cells) frequently grow out from the infundibulum ethmoidale into the agger nasi (Fig. 75) and are often referred to as agger cells (see pages 221 and 223).

The Nasal Atrium.—This is a shallow depression immediately inferodorsal to the nasoturbinal or agger nasi and in a sense may be considered its related meatus, and since it is a sort of an antespace to the middle nasal meatus is frequently referred to as the atrium of the middle nasal meatus.

The Olfactory Sulcus (sulcus olfactorius, carina nasi).—This is a cleft-like space developed between the agger nasi and the ental surface of the dorsum of the nose (dorsum nasi) and leads from the nasal vestibule to the olfactory part (pars olfactoria) of the nasal fossa (see page 97 and Fig. 146).

The Sphenoethmoidal Recess (recessus sphenoethmoidalis).—The sphenoethmoidal recess is developmentally related with the posterior cupola of the cartilaginous nasal capsule and is located cephalic and dorsal to the highest ethmoidal concha that may be differentiated and is limited by the angle formed by the cribriform plate of the ethmoid and the ventral surface of the sphenoid. From its dorsal boundary or wall develops the sphenoidal sinus and in later life contains the ostium or aperture of this sinus (Fig. 127).

Nomenclature.—From the foregoing it would appear that the general text-books of anatomy offer nomenclatures sufficiently extensive for adult conditions, but not for the late fetal and early infantile stages. The writer would, therefore, suggest the following terminology which covers not only adult conditions, but also the extreme ethmoidal differentiations found in infancy and late fetal life:

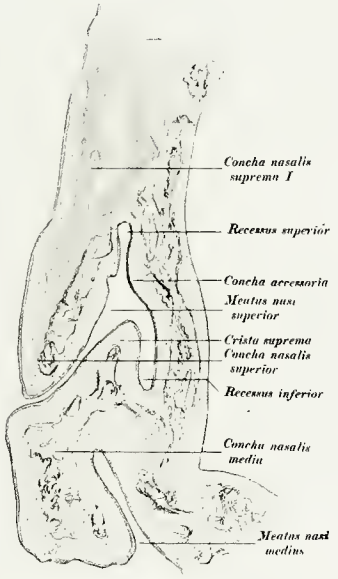

FIG. 34.—A frontal section through the lateral wall of the nasal fossa in the region of the superior nasal meatus (7-month fetus, series C, slide 8).
Especially note the accessory concha of the superior meatus and the crista suprema. × 10.

Conchæ nasales[1]	*Meatus nasi*
Concha nasalis inferior	Meatus nasi inferior
Concha nasalis media	Meatus nasi medius
Concha nasalis superior	Meatus nasi superior
Concha nasalis suprema I	Meatus nasi supremus I
Concha nasalis suprema II	Meatus nasi supremus II
Concha nasalis suprema III	Meatus nasi supremus III
Agger nasi	Atrium nasi

(B) **The Minor or Accessory Nasal Conchæ** (ectoturbinals, conchæ obtectæ) and **Meatuses or Furrows.**—Nasal conchæ and meatuses or furrows of a secondary or accessory nature are regularly differentiated and developed in the human nasal cavity and are homologous with analogous structures found in the mammalia, *e.g.*, rabbit, cat, etc. They are

[1] J. Parsons Schaeffer: The Lateral Wall of the Cavum Nasi in Man, with Especial Reference to the Various Developmental Stages, Jour. Morph., Vol. 21, No. 4, 1910.

intimately associated with the genetic history of the paranasal (accessory) sinuses and unless one has a clear conception of the origin and development of these early secondary structures found in the middle and superior nasal meatuses, it will be impossible to properly interpret the early prenatal and adult anatomy. Errors are repeatedly made in the analysis of the adult ethmoid labyrinth, the nasofrontal connections, etc., because adult and late fetal material alone are studied.

The accessory nasal conchæ and meatuses (folds and furrows) are located (1) in the descending ramus of the meatus nasi medius, (2) in the ascending ramus of the meatus nasi medius, and (3) in the descending ramus of the meatus nasi superior. These secondary or accessory struc-

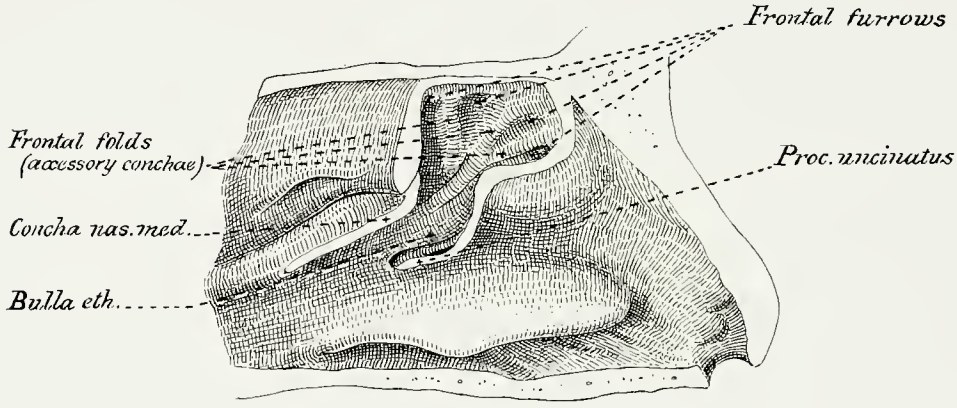

FIG. 35.—A dissection of the lateral nasal wall of a term fetus. The concha nasalis media has in large measure been removed thereby exposing the accessory folds or conchæ and furrows of the ascending (frontal recess) and descending rami of the meatus nasi medius. × 2.

tures are more or less hidden and operculated by the conchæ nasales media and superior:

1. **The Descending Ramus of the Meatus Nasi Medius.** —Serial frontal sections of the nose of 40-day embryos show that the lateral wall of the meatus nasi medius is even and unbroken. On the contrary, the same region in embryos aged from 40 to 60 days presents a crescentic-shaped fold breaking the evenness of the wall. This fold is the rudiment or anlage of the processus uncinatus and is the first of a series of accessory folds to appear on the lateral wall of the meatus medius. The fold at once aids in forming a furrow immediately superior to it—the **primitive infundibulum ethmoidale**. It is quite probable that the furrow first establishes a rudiment and this in turn throws into slight relief a portion of the mucous membrane inferior to it, thus establishing the anlage of the **processus uncinatus.** It may, however, be said that both structures are

more or less dependent upon each other in establishing rudiments. The same principles are obviously here involved as they are in forming the primitive major nasal meatuses and conchæ. From the primitive infundibulum ethmoidale, the sinus maxillaris develops its rudiment (65- to 70-day embryos) in the form of an evagination of the mucous membrane. This outpouching of the mucosa aids in early establishing the processus uncinatus and the infundibulum ethmoidale.

Shortly after this we have the first evidence of the bulla ethmoidalis, appearing superior and lateral to the processus uncinatus. The bulla ethmoidalis is first indicated by special thickenings (one or two) of the lateral plate of cartilage—the cartilaginous thickenings appearing on its medial surface. At first the bulla rudiments do not cause the mucous membrane to bulge toward the lumen of the nasal cavity and the early

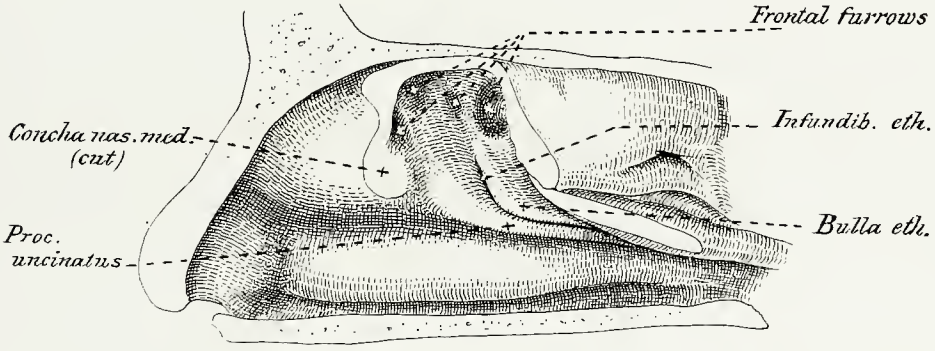

FIG. 36.—A dissection of the frontal recess of a term fetus showing the early frontal furrows; *e.g.*, rudiments of anterior ethmoidal cells and potential rudiments of the frontal sinus. Particularly, note the relations of the infundibulum ethmoidale. × 1.5.

stages pass unobserved unless one examines serial frontal sections through the region. Later, however, say in a 120-day embryo, the cartilaginous prominences have developed sufficiently to push the mucous membrane on the lateral wall of the meatus medius into relief and to establish a fold, or folds (bullar folds), lateral and superior to the processus uncinatus. If two folds appear there is an intervening furrow and occasionally an ethmoidal cell develops from it. The folds represent the primitive bulla ethmoidalis which usually merge before or after birth in the formation of the definitive bulla ethmoidalis (Figs. 33 and 38).

Thus far no mention has been made of another fold that appears in many instances inferior to the bullar folds and lateral to the infundibulum ethmoidale. Because of its relations to the infundibulum ethmoidale it is appropriate to speak of this as the infundibular fold. It is never very

prominent and forms in part the lateral wall of the infundibulum ethmoidale. It may persist as a fold after birth, but it generally becomes leveled down to an even surface which imperceptibly passes on to the bullar surface.

The **minor or accessory conchæ or folds** of the descending ramus of the middle meatus may appropriately be named the superior and inferior bullar folds, the infundibular fold and the processus uncinatus; the **accessory furrows,** the suprabullar furrow or recess, the bullar furrow, the infrabullar furrow, and the infundibulum ethmoidale. The suprabullar recess and the infundibulum ethmoidale are constant and important furrows. The others are of little importance and are irregular and inconstant in their development:

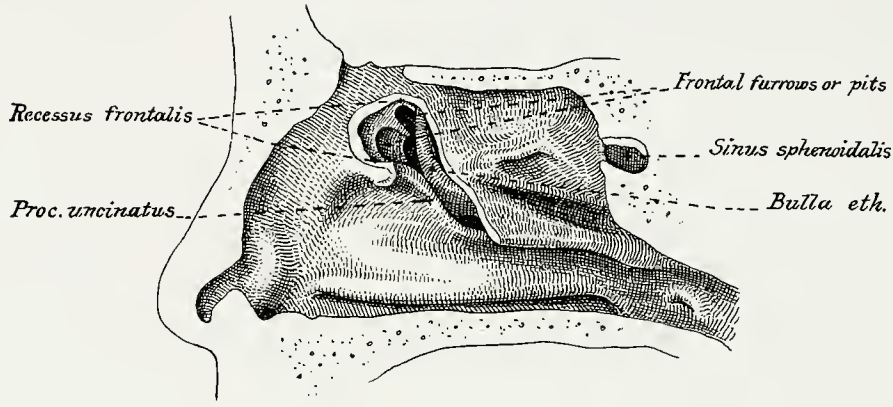

FIG. 37.—A dissection of the frontal recess, etc., of a child aged 5 months. Note the pouching of the frontal furrows and the frontal recess in the formation of anterior ethmoidal cells and the frontal sinus. The sphenoidal sinus is also well established. × 1.5.

The suprabullar furrow or recess is practically constant. It varies somewhat in its form and extent, but all specimens give some evidence of it. At times it continues ventrally and superiorly, almost to the cribriform plate of the ethmoid bone; however, in the majority of cases it does not extend so far, due to partial fusion between the superior border of the superior bullar fold and the attached border of the concha media. It is frequently also limited inferiorly and dorsally by similar fusion. Again, there may be multiple points of fusion between the superior bullar fold and the concha media, thus breaking the suprabullar recess or furrow into several compartments (Fig. 40). The recesses in many cases early tend to deepen and pouch laterally and inferiorly behind the bullar folds. In this manner the bulla becomes more or less shell-like in structure and some of the so-called bullar cells established. The suprabullar recess is a constant point from which anterior ethmoidal cells develop.

The bullar furrow is placed between the two bullar folds or accessory conchæ. It is variable in its differentiation and not at all constant. It is generally obliterated by the superior and inferior bullar folds becoming continuous structures in the formation of the adult bulla ethmoidalis. This coalescence is, however, not always absolute in that an ethmoidal cell may develop from the furrow, leaving the ostium of the adult cell at the point of the primitive furrow. Even in many adult specimens one finds evidence of this primitive furrow in the form of a shallow groove on the medial surface of the bulla ethmoidalis. An ethmoidal-cell ostium on the medial surface of the bulla ethmoidalis is almost invariably the remains of the early bullar furrow.

The infrabullar furrow is placed between the inferior bullar and the infundibular folds. It is very inconstant and not infrequently obliterated

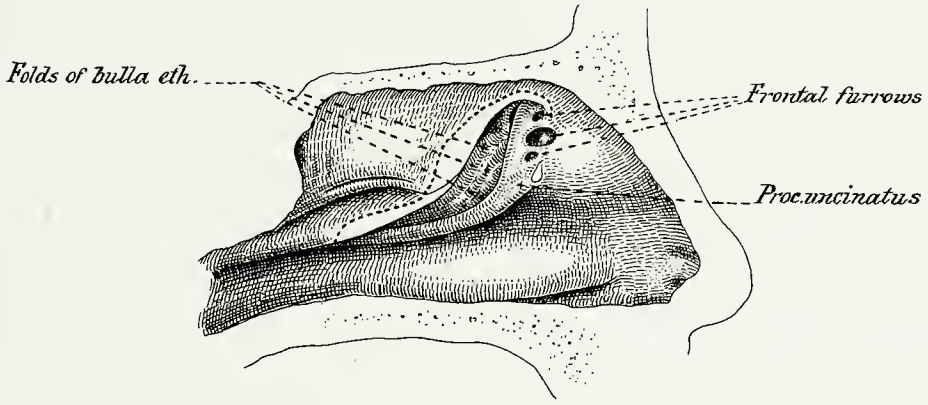

FIG. 38.—The lateral nasal wall of a term fetus. The concha nasalis media is cut away, thereby exposing the folds of the bulla ethmoidalis, the processus uncinatus and the frontal folds and furrows for study. (See text.)

by the inferior surface of the bulla ethmoidalis becoming continuous with the infundibular fold. In some cases it is fairly well marked, but as a rule is of minor importance. Rarely an ethmoid cell develops from the furrow—the adult cell draining into the infundibulum ethmoidale (Figs. 33 and 35).

The infundibulum ethmoidale is invariably present in some form. It is formed early and obviously aids in establishing the primitive processus uncinatus. It is directed somewhat ventro-superiorly and at its ventral and superior termination may end blindly or develop into an anterior ethmoid cell. At other times it is variously continued into one of the frontal furrows. Rarely it continues its development ventrally and superiorly, remaining lateral to the frontal furrows and in this way may establish the

frontal sinus (Figs. 36 and 127). Dorsally and inferiorly it either gradually loses its depth and thus becomes continuous with the middle meatus, or it ends rather abruptly in a pocket, due to the superior and lateral curving of the dorsal end of the processus uncinatus at this point. From the infundibulum ethmoidale the sinus maxillaris develops, hence in the adult the latter sinus communicates with the infundibulum ethmoidale and only indirectly via the hiatus semilunaris with the meatus nasi medius.

The superior bullar fold or concha is located immediately inferior to the suprabullar recess. It may continue independently ventrally and superiorly almost to the cribriform plate of the ethmoid bone. In other instances it is fused at certain points with the attached border of the concha

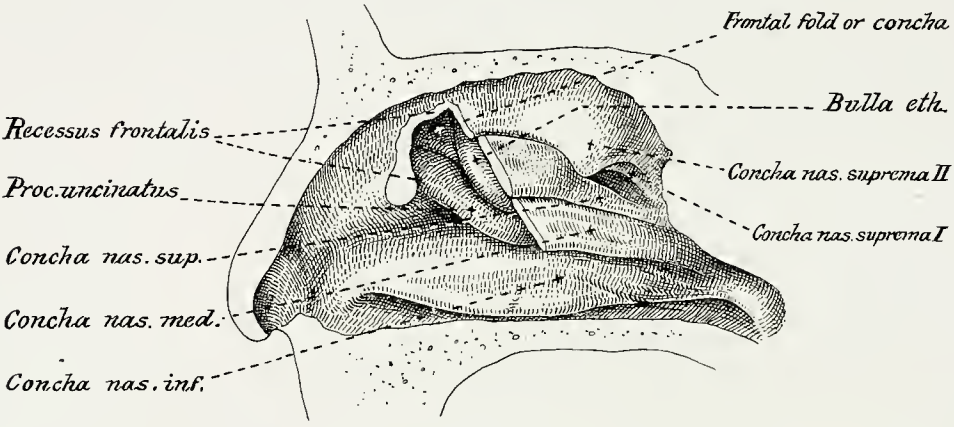

FIG. 39.—A frontal recess in which a single frontal fold or concha has been differentiated. Note the continuity of the infundibulum ethmoidale with the furrows, frontal furrows, bordering the frontal fold. Compare this condition with Fig. 36. × 1.5.

nasalis media. It is frequently continuous with one or more frontal folds. The superior bullar fold usually comes to form the chief bulk of the adult bulla ethmoidalis. In many cases there is no differentiation into superior and inferior bullar folds by an intervening furrow—the bullar furrow (Figs. 33 and 39).

The inferior bullar fold or concha is, as stated above, not always differentiated from the superior bullar fold. It is, however, occasionally well isolated and stands more or less as an independent fold. The latter condition is especially marked in the cases where an anterior ethmoidal cell develops from the bullar furrow. The writer agrees with Killian that the superior and inferior bullar folds (obere und mittlere Nebenmuscheln, Killian) usually coalesce to form the adult bulla ethmoidalis. Sometimes, even in the adult, one sees evidences of the primitive bullar furrow which more or less grooves the medial surface of the adult bulla. In many

instances, however, coalescence is not necessary because there was at no time a differentiation into two portions.

The infundibular fold or concha is very rudimentary and more or less inconstant. It is located lateral to the infundibulum ethmoidale and in part forms its lateral wall. It is more or less separated from the inferior bullar fold by the shallow infrabullar furrow. It usually loses its identity in the adult in that it imperceptibly passes to the bullar surface by the obliteration of the infrabullar furrow. Occasionally it is well marked and more or less isolated from the inferior bullar fold by a relatively deep infrabullar furrow. Rarely it retains its identity in the adult—this is especially so when an anterior ethmoidal cell develops from the infrabullar furrow.

The processus uncinatus is a constant structure, and is medial and inferior to the infundibulum ethmoidale. As stated before, it is the first of the accessory or hidden conchae to be differentiated. At its ventral and superior end it terminates in various ways. In some cases it is continuous with one or more frontal folds and at the same time its base continued on to the agger nasi. In other instances it is fused with the lateral surface of the concha media at its ventral extremity or even fused with the ventral extremity of the bulla ethmoidalis. Ventrally and inferiorly the base of the processus uncinatus becomes continuous with the surface of the agger nasi. Some observers erroneously class the processus uncinatus with the major ethmoidal conchæ (Figs. 22 and 25).

2. **The Ascending Ramus of the Meatus Nasi Medius** (the recessus frontalis).—The extension of the middle meatus toward the frontal region is the first step in the formation of the frontal sinus and certain of the anterior ethmoidal cells. To this extension or recess Killian[1] has given the appropriate name, "recessus frontalis." For some time the lateral wall of this recess (ascending ramus of the middle meatus) is even and unbroken. Frontal and horizontal sections of the recess of a 4-month fetus reveal the lateral plate of cartilage thickened at certain points in the form of projections directed toward the lumen of the nasal fossa. For some time this condition prevails and the mucous membrane is not at first thrown into relief. These thickenings vary in number and are in anticipation of the accessory conchæ which are present on the lateral wall of the frontal recess of later fetuses.

The frontal folds or conchæ and the frontal furrows of the frontal recess of the late fetus are variable in number and as a rule are not very prominent. Their prominence depends largely upon the degree of devel-

[1] Anatomie der Nase menschlicher Embryonen, Archiv f. Laryngolog., 1896.

opment of the intervening furrows or pits (frontal furrows). The conchæ or folds as a rule more or less lose their identity after birth, and the furrows or pits variously remain as ostia of anterior ethmoidal cells and the point of communication of the frontal sinus.

As stated above the frontal conchæ or folds and furrows vary in degree of development and differentiation. Specimens with four well-formed furrows and three resulting folds are not uncommon. In other cases, either by early coalescence or lessened differentiation, fewer folds and furrows are found. The first and second frontal folds or conchæ are at times confluent with the processus uncinatus (Fig. 36) and in addition occasionally extend toward the agger nasi with which they are confluent,

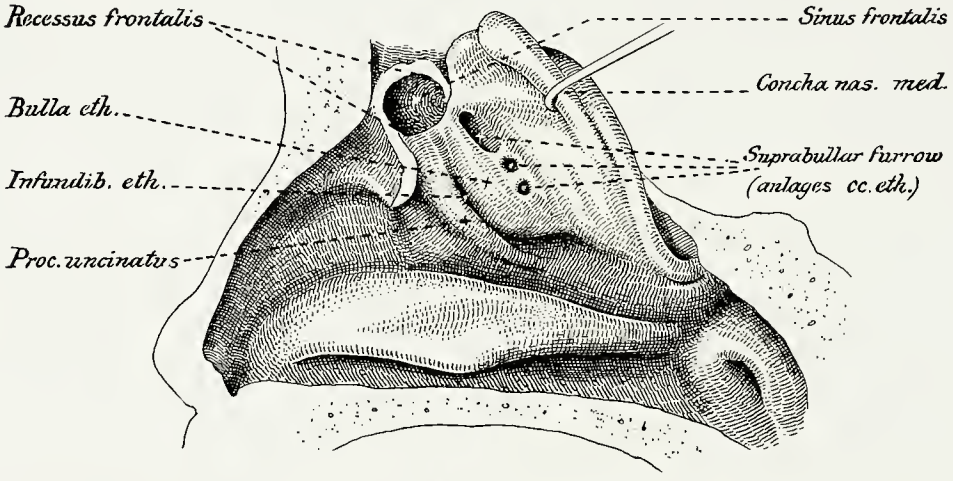

FIG. 40.—A dissection from a child aged 14 months with the concha nasalis media turned aside. Apparently no frontal folds nor furrows were differentiated and the whole frontal recess is expanding toward the frontal region in the establishment of the frontal sinus. Note that the infundibulum ethmoidale and the recessus frontalis are discontinuous anatomically; moreover, that the suprabullar furrow is represented by a series of depressions, rudimentary cellulæ ethmoidales. × 0.8.

moreover touch the lateral surface of the concha nasalis media with which they fuse. In Fig. 35 is represented a specimen in which the processus uncinatus is continued ventrally and cephalically to the agger nasi, in part fusing with the concha nasalis media at this point. The superior and inferior bullar folds in the latter instance are continued superiorly to become continuous with the first and second frontal folds. The third frontal furrow is more or less continuous with the suprabullar recess, and the latter continues almost to the cribriform plate of the ethmoid bone. The infundibulum ethmoidale continues ventrally and cephalically into a frontal furrow. Compare this condition of the infundibulum ethmoidale with that found in Figs. 36, 39 and 40.

In Fig. 39 there is only one frontal fold or concha differentiated.

The concha is bordered by two frontal furrows, and the infundibulum ethmoidale is continued ventrally and superiorly into these furrows. In Fig. 38 the processus uncinatus is continued ventrally on the lateral wall of the frontal recess and apparently the frontal folds extend from it. At times the frontal folds or conchæ fuse with the lateral surface of the concha nasalis media and obliterate the frontal recess as such. In these cases the sinus frontalis must develop from an anterior ethmoidal cell, and not by direct extension of the frontal recess (Fig. 150). In Fig. 147 the frontal folds have not fused with the lateral surface of the concha nasalis media, the frontal recess being maintained. In such a condition the sinus frontalis may develop either from the frontal recess or from one or more anterior ethmoidal cells. It is difficult to say in the latter dissection whether the frontal folds or conchæ have coalesced with one another, thus constricting off small blind pouches (early anterior ethmoidal cells), or whether the frontal furrows in anticipation of anterior ethmoidal cells have pouched toward the frontal region, thus closely simulating coalescence between the several frontal folds, but making coalescence apparent rather than real.

(3) **The Descending Ramus of the Meatus Nasi Superior.**—At this juncture mention must again be made of a frequent accessory concha differentiated rather early and well established by the fourth month of fetal life on the lateral wall of the descending ramus of the meatus nasi superior. In specimens where the accessory concha of the superior meatus is well developed, fairly well formed *superior* and *inferior recesses* are established on the lateral meatal wall. The inferior recess is especially deep in the cases where the "crista suprema" of Killian is well developed. This condition makes the superior meatus look much like the middle meatus, *i.e.*, the accessory concha of the superior meatus takes the place of the bulla ethmoidalis (accessory concha of the middle meatus), and the "crista suprema" takes the place of the processus uncinatus (compare Figs. 21 and 34).

The inferior recess of the superior meatus may continue ventrocephalically into the blind superior termination of the superior meatus. The accessory concha is, however, at times wholly or in part coalesced with the concha media, thus obliterating wholly or partly the inferior recess. Frequently a posterior ethmoidal cell develops from the inferior recess. The superior recess is often obliterated by coalescence between the accessory concha and the concha superior. In other instances the superior recess too is continued ventrocephalically to the blind end of the meatus superior. Occasionally an ethmoidal cell develops from this recess.

(C) **The Rudiments or Anlages of the Paranasal** (Accessory) **Sinuses.**—The paranasal sinuses are preformed in the major and minor nasal meatuses (none develop from the meatus nasi inferior). This is true for all the paranasal sinuses save the sphenoidal which arises in connection with the posterior cupola of the cartilaginous nasal capsule, and in a sense is primarily a constriction of the nasal mucosa from the dorsocephalic part of the nasal fossa.

After the preceding consideration of the nasal meatuses and conchæ and the accessory conchæ and furrows, the genesis of the paranasal sinuses becomes much simplified and fairly easy of interpretation. Since the paranasal or accessory sinuses develop from preformed furrows and recesses, it is difficult to say just when they have established rudiments. The author believes, however, that rudiments are established much earlier than is generally supposed. Indeed, the furrows and recesses from which the paranasal sinuses develop are, in a sense, the "primitive" rudiments of these chambers. The early tendency for the sinuses to establish their "first" rudiments may be no mean factor in making the recesses and furrows what they early are.

The pre-existing spaces from which paranasal air chambers develop, according to the writer's specimens and studies, are: (1) the suprabullar recess, (2) the bullar furrow, (3) the infrabullar furrow, (4) the infundibulum ethmoidale, all of the descending ramus of the meatus nasi medius; (5) the frontal furrows, (6) the frontal recess, both of the ascending ramus of the meatus nasi medius; (7) the ventral and superior extremity of the meatus nasi superior, (8) the recessus superior, (9) the recessus inferior, all of the meatus nasi superior; (10) the meatus nasi supremus I. Of the foregoing named spaces, paranasal sinuses or cells rarely develop from the infrabullar furrow and only occasionally from the bullar furrow. Posterior ethmoidal cells develop rather frequently from the inferior and superior recesses of the meatus nasi superior, and in about 75 per cent. of specimens in which the meatus supremus I persists, a posterior ethmoidal cell develops from it (the meatus nasi supremus I is present in about 62 per cent. of adult specimens). The remainder of the aforementioned spaces are practically constant in the development of paranasal sinuses or cells.

The paranasal sinuses as such are primarily evaginations of the nasal mucous membrane in fairly definite regions of the nasal meatuses mentioned. These early evaginating sacs wander into neighboring portions of the nasal walls by a joint growth of the sacs and an absorption of bone, until goodly portions of the ethmoid, frontal, maxillary and sphenoid bones are pneumatized in the formation of the cellulæ ethmoidales, the sinus fron-

talis, the sinus maxillaris, and the sinus sphenoidalis, respectively. The conchal cells are, of course, outlying ethmoidal cells and in their origin and development are in all respects in agreement with the ethmoidal cells proper. In some cases, particularly the ethmoidal cells, ossification of the cartilaginous walls of the mucous membrane sacs takes place around the cells, the point of original outgrowth remaining as the permanent ostium of the respective cell. Indeed, no matter how far a cell or sinus may grow into a neighboring bone, its initial point of outgrowth from the nasal fossa persists in the adult as the ostium of the cell or sinus.

In subsequent paragraphs each paranasal sinus and groups of cells will be discussed under three heads: (1) the fetal stage, (2) the childhood stage, and (3) the adult stage. In order that there may be no unnecessary repetition a further consideration of the early anatomy of the paranasal sinuses as exhibited in the fetus will be deferred for discussion in connection with the sinus concerned.

The Definitive Nasal Septum

The median frontonasal process, one of the "trabeculæ cranii," is early divided into two lateral processes (lateral nasal processes) and two

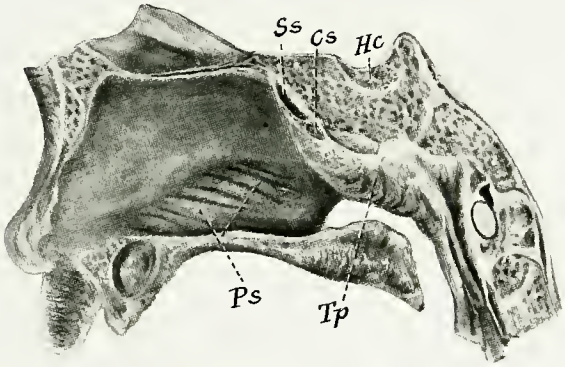

Fig. 41.—The nasal septum of a child aged 18 months. Particularly note the septal plicæ (plicæ septi) and the sinus sphenoidalis. × 0.7.

Ps. = plicæ septi; Tp. = tonsilia pharyngea; Ss. = sinus sphenoidalis; Cs. = concha sphenoidalis; Hc. = hypophysis cerebri.

mesial processes (mesial nasal processes). These form the walls of the primitive nasal fossæ. The mesial nasal processes fuse in the formation of the central portion of the upper lip, the premaxillary process (not to be confused with a premaxillary bone), and the primary nasal septum. Subsequently, as stated elsewhere, and coincidently with other changes, the primary nasal septum grows dorsally toward the pharynx and caudally toward the mouth in the formation of the secondary nasal septum,

ultimately fusing with the nasal surface of the palate and forming a free border dorsally between the definitive choanæ or posterior nares. It is, therefore, obvious that the definitive or final nasal septum is made up of primary and secondary portions, both derivatives of the mesial part of the frontonasal process.

The primary nasal septum is at first thick, separating widely the early olfactory fossæ, the secondary septum relatively thin. The definitive nasal septum gradually becomes thinner and thinner, the nares coming to occupy positions nearer the mid-plane, and a laminar plate of cartilage develops in its substance. A fairly heavy mucous membrane covers both surfaces of the septum, part of which forms a paired tubular organ in the ventrocaudal portion of the septum immediately dorsal and cephalic to the incisive foramen (the vomeronasal organ). The glands of the nasal mucosa develop as solid processes during the third and fourth months, but do not reach their complete development until after birth. Moreover, the mucous membrane of the nasal septum of the fetus usually presents well-developed folds in the region of the later vomer (septal folds, plicæ septi). The author has frequently noticed a preponderance of epithelial thickness in this region of the septum as early as the third month of uterine life. The septal folds and intervening furrows increase in size until the seventh or eighth month, then undergo a retrograde metamorphosis. They usually disappear in early infancy. However, the septal plicæ may persist, even hypertrophy and form tumor-like obstructing masses in the adult (Fig. 41).

Portions of the laminar plate of cartilage remain and form the septal cartilage and the vomerine cartilages, and other parts are replaced by bone. It is, therefore, obvious that the nasal septum passes through three distinct stages: (1) the membranous, (2) the cartilaginous, and (3) the adult mixed cartilaginous and osseous (see pages 78 and 81).

The Development of the Nasal Skeleton

(A) **The Cartilaginous Nasal Capsule.**—The nasal capsule and the ethmoidal region are the last portions of the chondrocranium to become cartilaginous (Fig. 42). Generally speaking, the nasal capsule and the ethmoidal region are membranous as late as the eighth month of embryonal life (20 mm. embryos); however, the lateral wall of the nasal capsule and the nasal septum are obviously in the precartilage stage as evidenced by mesenchymal condensation. By the middle of the third month of embryonal life the nasal capsule is well advanced as a cartilagi-

nous structure. Cartilage extends into the nasal septum from the body of the sphenoid. The lateral walls of the nasal cavity chondrify independently, later joining the nasal septum ventrally to form the cartilaginous roof and lateral walls of the nasal cavity. Subsequently, the lateral cartilaginous walls connect up dorsally where the sphenoidal and septal cartilages are confluent. The inferior margin of the lateral cartilage infolds behind the naris and becomes the cartilage of the maxillo (inferior)-turbinate. This infolding, at first simple, becomes more complex by the formation of accessory processes and folds. During the seventh month

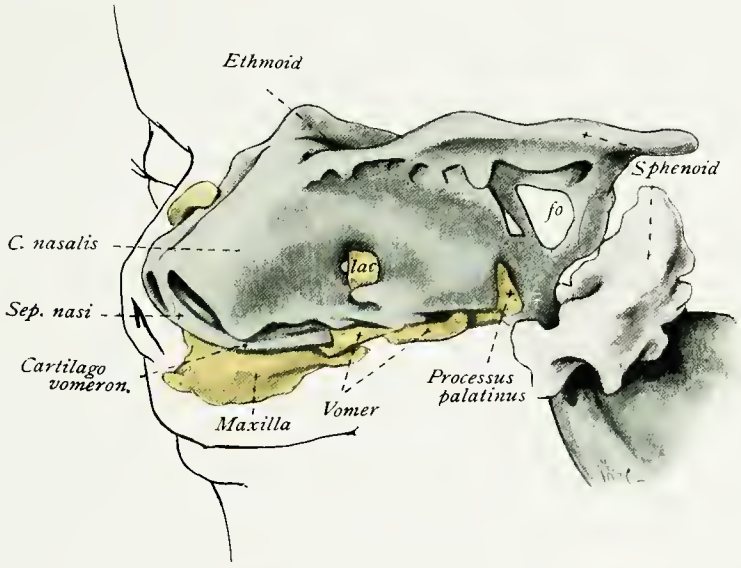

FIG. 42.—The cartilaginous nasal capsule from a human fetus aged 4 months. (*Adapted from Kollmann.*)

fo = foramen opticum; *C. nasalis* = capsula nasalis; *lac.* = lacrimal.

it becomes separated from the lateral wall. In the adult the maxillo (inferior) turbinate (concha nasalis inferior) is an independent bone.

The early membranous conchal (turbinal) folds, comprised of epithelium and underlying mesenchyme, develop cores of precartilage (condensed mesenchyme). The condensed mesenchymal cores chondrify during the fourth month of embryonal life. As stated before, the initial conchal or turbinal folds are not due to an inpushing of the mucosa by the cartilaginous strands, *e.g.*, cartilage develops within the folds, but does not grow into them (see page 19 and Figs. 14 and 15).

During the third month of fetal life a short, stumpy cartilaginous process (processus paranasalis) arises from the lateral wall of the cartilaginous nasal capsule to surround the developing nasolacrimal duct.

The fate of the several portions of the cartilaginous nasal capsule varies. Certain parts persist and are carried over as cartilage into the skeleton of the adult nose (the cartilaginous portion of the septum and the cartilages of the external nose); others become ossified as individual bones to participate in the formation of the adult nasal skeleton (the ethmoid bone, including the ethmoturbinals, the maxilloturbinal, and the sphenoturbinal); and, thirdly, some portions are soon overlaid by connective tissue osseous rudiments or anlages and the cartilage for the most part absorbed. For example, parts of the septum and of the lateral wall above the maxilloturbinal disappear and are replaced by parts of the neighboring membrane bones. Moreover, the original continuity of the cartilaginous nasal capsule is broken by division into smaller portions brought about by the ingrowth of connective tissue at various points. This leads during the sixth month to the formation of the individual alar cartilages and the detachment of the cartilaginous nasal septum from the anterior portion of the lateral cartilage. Posteriorly the connections with the lateral cartilage are retained.

(B) **Ossification of the Elements that Participate in the Boundaries of the Cavum Nasi.**—In this connection it will be necessary to consider parts that arise in relation with the cartilaginous nasal capsule and others which from a developmental standpoint are not related.

1. **The Ethmoid Bone** (os ethmoidale).—The greater portion of the posterior part of the cartilaginous nasal capsule becomes the ethmoid bone. The lateral and one medial primary and several secondary ossification centers appear in the capsule. Each lateral center appears in the fifth or sixth fetal month and gives rise to an orbital plate (os planum, lamina papyracea), ossification extending into the lamina cribrosa and into the ethmoturbinals during the seventh and eighth months. In this manner permanent osseous foramina are formed for the olfactory nerves and the mucosa-walled ethmoidal air cells gain bony boundaries. During the first year of postfetal life ossification begins in the cephalic portion of the cartilaginous nasal septum to form the lamina perpendicularis of the ethmoid and extends into the crista galli and the cribriform plate. Secondary centers appear later. The date of the bilateral union of the three pieces (lamina cribrosa, lamina perpendicularis and lamina papyracea) is uncertain. A study of a few specimens would indicate that the fusion takes place late in the sixth year. The ethmoidal cells are primarily evaginations of the nasal mucosa which grow into the lateral ethmoidal masses and their appendages (the ethmoturbinalia) and by further growth of the sacs and the absorption of bone become well established as the cellu-

lar ethmoidal labyrinth. The ossification of the ethmoid is not completed until the end of the seventeenth year. The lamina perpendicularis ultimately (45 to 50 years) unites with the vomer. The posterior dome or cupola of the cartilaginous nasal capsule in man ossifies as the sphenoidal turbinate or concha (ossiculum Bertini).

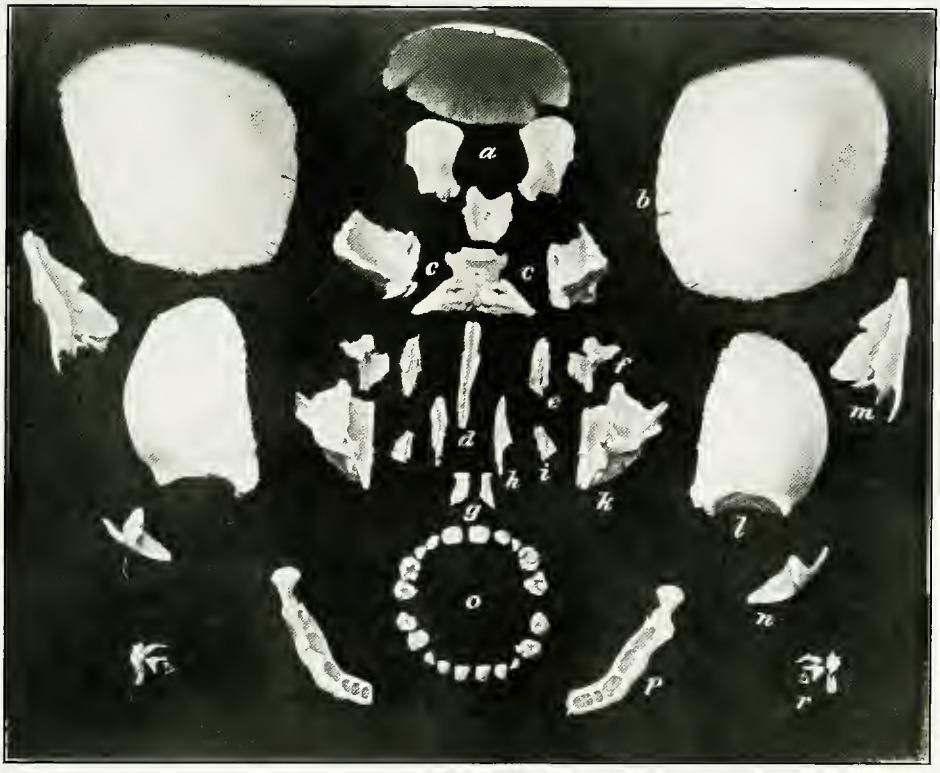

FIG. 43.—A photograph indicating stage of development of the osseous elements of the head in a fetus at term. ×0.45. (*Courtesy of Mütter Museum, College of Physicians.*)
a = occipital; *b* = parietal; *c* = sphenoid; *d* = vomer; *e* = ethmoid; *f* = palate; *g* = nasal; *h* = inferior turbinate; *i* = lacrimal; *k* = maxilla; *l* = frontal; *m* = temporal; *n* = zygomatic; *o* = dentes; *p* = mandible; *r* = ear ossicles.

2. **The Vomer.**—The true vomer develops bilaterally on each side of the caudal and dorsal portion of the cartilaginous nasal septum from a pair of ossification centers during the eighth week of fetal life. This is in agreement with Mall. These centers unite beneath the caudal border of the septal cartilage, but grow cephalically on each side of the septum as two plates, thus enclosing the cartilage. The bilateral plates of the vomer unite from behind forward at the expense of the imprisoned cartilage, union being completed by the fifteenth year. The vomer of the young infant shows clearly its formation in two plates (Fig. 43). In the adult,

on the other hand, the bilaterality of the vomer is indicated merely by the groove between the alæ and by the groove on the lower part of the ventral border where it receives the triangular septal nasal cartilage. In spite of the fact that the vomer develops on each side of the cartilaginous nasal septum and at its expense, it must be classed as a true membrane bone. Rarely a patch of cartilage persists between the bilaminar vomer and develops into a chondroma subsequently.

3. **The Maxilloturbinal** (concha nasalis inferior).—The inferior nasal concha or turbinal arises in cartilage from the lower inturned border of the lateral plate of the cartilaginous nasal capsule. It develops from a separate ossific center which appears about the middle of fetal life.

4. **The Palate Bone** (os palatinum).—The palate is a membrane bone arising according to recent studies from a single ossification center located at the junction of the horizontal and vertical portions of the bone (Mall[1] and Fawcett[2]). The ossific center appears at the end of the second month of fetal life. The vertical portion of the palate bone extends upward on the medial surface of the lateral wall of the cartilaginous nasal capsule; the latter intervening, therefore, between the palate bone and the maxilla. At a subsequent period the intervening cartilage undergoes resorption. The horizontal part ossifies in the dorsal portion of the definitive palate which it helps to form.

5. **The Nasal Bone** (os nasale).—The nasal bone is bilaterally present and develops in membrane on the surface of the cartilaginous nasal capsule. The subjacent cartilage can be demonstrated as late as the first month of postfetal life, then becomes absorbed. It is generally believed that the bone develops from a single ossific center. Perna (1906)[3] believes that the nasal bone develops from two rudiments, a lateral membranous and a small median cartilaginous. A small Wormian bone may develop in the median line between the nasals and the frontal. Ape-like the two nasals sometimes coössify. Bilateral and unilateral absence of the nasal bone occurs (see page 65 for a consideration of the variations of the nasal bones).

6. **The Lacrimal Bone** (os lacrimale).—The lacrimal bone arises in membrane on the lateral wall of the cartilaginous nasal capsule. It ossifies from one or more centers which appear during the third month of fetal life. The adult bone is occasionally divided. According to Mall

[1] On centers of ossification in human embryos less than 100 days old, Amer. Jour. Anat., Vol. 5, 1896.

[2] On the development, ossification, and growth of the palate bone of man, Jour. of Anat. and Physiol., Vol. 40, 1906.

[3] Die Nasenbeine, Arch. f. Anat. u. Physiol. Anat. Abt., 1906.

the bone ossifies from one center which appears on the eighty-third day.

7. **The Sphenoid Bone** (os sphenoidale).—The sphenoid bone is in part preformed in cartilage and in part in membrane. Ten principal centers of ossification arise in the cartilage that corresponds to this bone, one for each great wing during the eighth week of fetal life (alisphenoid), one for each small wing (orbitosphenoid), two for the body between the great wings during the early part of the third month of fetal life (basisphenoid), two for the body between the small wings during the second month (presphenoid), and one for each lingula during the fourth month.

Membrane bone forms the orbital and temporal portions of the great wings and the medial laminæ of the pterygoid processes (the hamular processes excepted).

The presphenoid and the lesser wings unite before birth. About the eighth month of fetal life the pre- and basisphenoids unite, but at birth and for sometime longer these parts are still separated by cartilage on their inferior surfaces. During the first year of postfetal life the several parts of the sphenoid coalesce.

The sphenoturbinals in the adult are fused to the ventral surface of the body of the sphenoid bone and form the ventral boundaries of the paired sphenoidal sinuses. Developmentally, however, these turbinals are separate and individual bones and merit further discussion. The embryology and anatomy of the sphenoidal sinuses will be discussed in other paragraphs (see Chapter V).

8. **The Sphenoturbinal** (concha nasalis sphenoidalis, ossiculum Bertini).—The sphenoturbinal bone is a bilateral, thin, cap-like plate which appears before birth at the front of the presphenoid. It develops as an independent element from ossific centers associated with the posterior cupola of the cartilaginous nasal capsule during the latter half of fetal life. The centers appear in the medial and lateral walls of the cupola, later to be connected by secondary ossific centers in the membranous portion of the cupola toward the termination of fetal life. At the time of the third year the cupola-shaped recess or terminal nasal sinus (the early sphenoid sinus) is surrounded by bone and lined with nasal mucosa, except toward the nasal fossa, where an opening or ostium persists (the primary ostium sphenoidale or opening into the sphenoidal sinus). The sphenoturbinals cover the ventral and caudal surfaces of the presphenoid and at five years are still free from the sphenoid bone, membranous tissue intervening (Fig. 132). During the fourth year,

however, the cephalic and medial parts of the nasal capsule begin to be absorbed and then the presphenoid participates in bounding the terminal nasal sinus, *e.g.*, the sinus sphenoidalis. This gives the sphenoidal sinus an opportunity to grow into the body of the sphenoid bone, and the sphenoturbinals instead of presenting rounded openings in the disarticulated bone present notches. The persistent portions of the sphenoturbinals unite first (fifth year) with the ethmoid and ultimately (ninth to twelfth year) with the sphenoid and palate bones. Their identity and individuality is from then on lost.

9. **The Maxilla.**—Cartilage fails to appear in the maxillary process of the first branchial arch due probably to the rapid development of the parts concerned, wherefore the palate bone and the maxilla arise directly in membrane. Ossification of the maxilla commences in the sixth or seventh week of embryonal life as one center (Hertwig, Mall, Schaeffer) from which an ossifying process soon extends toward the frontal bone in the formation of the frontal process of the maxilla. Later extensions from the primary ossific center develop into the orbital, alveolar, and palatine processes. Moreover, a single ossific center appears in the related half of the intermaxillary mass which establishes union with the center in the maxilla proper early in the third month of fetal life. Albrecht erroneously believed that each premaxilla was made up of two bones. According to Mall both the centers of the premaxilla and the maxilla participate in the formation of the frontal process.

Initially, the maxilla lies ectal to the cartilaginous nasal capsule. Subsequent absorption of a goodly portion of the nasal capsule allows the maxilla to participate in forming the lateral nasal walls, to complete the osseous boundaries of certain ethmoidal cells, to articulate with the maxilloturbinal, and to become the bone for the reception and development of an evaginating nasal-mucous-membrane pouch destined to become the sinus maxillaris (antrum of Highmore). The formation of the alveolar process begins as early as the fourth fetal month, but is not completed until the twenty-fourth year.

It will be recalled that in the third or fourth month a stumpy cartilaginous process (processus paranasalis) arises from the lateral wall of the cartilaginous nasal capsule and surrounds the developing nasolacrimal duct. Apropos of this, one frequently finds cartilaginous masses in the alveolar part of the developing maxilla which have no connection with the nasal capsule. Mihalkovics suggests (1899) that these masses of cartilage are portions of the processus paranasalis caught in the ossifying maxilla. The masses usually disappear.

The infraorbital vessels and nerve occupy for some time a mere groove on the orbital surface of the maxilla, later to become encased by an ingrowth over them of a lamina of bone. At times the osseous floor of the infraorbital canal remains deficient and the nerve and vessels are then separated from the cavity of the maxillary sinus merely by the mucous membrane. The sinus maxillaris in its relations to the maxilla and to the deciduous and permanent teeth will be discussed subsequently (see Chapter III).

10. **The Frontal Bone** (os frontale).—The frontal bone participates to a limited degree in bounding the nasal cavity and is the bone of reception for the evaginating mucous-membrane sac or sacs from the frontal recess of the middle nasal meatus to become topographically the frontal sinus or sinuses.

The bone is developed in membrane. According to the studies of Mall,[1] in which the writer concurs, in the region of the future frontal eminences appear during the eighth week two major ossific centers. Additional centers at times appear. At birth the frontal bone is divided into right and left halves which become approximated during the first year and fuse along the metopic suture during the second year. This fusion may be delayed until the seventh or ninth year or may never take place. The metopic suture may persist throughout or may be retained at its lower extremity; then forming a metopic fontanelle. Wormian bones (ossa metopica) may develop in the region of the metopic fontanelle during the process of ossification. Metopic ossicles may develop in other parts of a persistent metopic suture.

The frontal sinus begins to develop during the fourth or fifth month of fetal life in the region of the frontal recess of the middle nasal meatus, but is not topographically frontal until some time after birth. It develops slowly until the seventh or eighth year, then more rapidly up to the twentieth year and increases somewhat in size up to old age. A persistent metopic suture precludes the development of a frontal sinus beyond the mid-sagittal plane; at least this is true in all such skulls observed by the writer (Fig. 66).

(C) **Skeleton Changes Incident to Growth.**—At birth the facial skeleton is relatively small due in part to the small size of the nasal fossæ and maxillary sinuses. The nasal fossæ are as wide as they are high. The bony nasal aperture is relatively broad and its caudal border but little below the plane of the orbit. Moreover, the nasal aperture and cavity are not clearly separated from the face. The bony choanæ (posterior

[1] Loc. cit.

nares) are relatively small, 5 to 7 mm. in the vertical diameter and 7 to 8 mm. in the transverse (coronal). By the sixth month of extrauterine life the choanal diameters have doubled; however, the diameters remain such as to give more or less circular choanæ. After puberty the vertical diameter is always greater than the transverse and the shape of the choanæ is changed from circular to oblong. This change in the diameters of the choanæ is due to unequal growth: At birth the dorsal border of the hard palate is on a plane with the occipito-sphenoidal articulation; during the third year it drops to the mid-plane of the basi-occipital, and by the sixth year is essentially in the adult plane, *e.g.*, the ventral border of the foramen magnum.

It will be recalled that the maxillary turbinal field of the early nasal fossa occupies almost the entire lateral wall (Fig. 17). Later the ethmoidal turbinal field begins to be formed and soon outdistances the maxillary in the extent of its vertical plane. Indeed, at birth, as shown by Kallius, the ethmoidal part of the nasal fossa is twice the height of the maxillary in spite of the fact that in the adult the two portions are equal. This means that the maxillary portion grows faster after birth, catching up approximately the seventh year when the adult relations are attained. Dentition and the development of the maxillary sinus may have some bearing on this relationship. The inferior meatus remains very narrow until after the deciduous teeth have erupted. Before this, owing to a relatively large inferior concha, there is little room in the inferior meatus for the passage of air—the concha almost touching the floor of the nose (see maxillary sinus, page 107).

The skull at birth shows a relatively large cranial portion and a small facial when compared with the skull of the adult. Froriep estimated the ratios to be 8 : 1 in a "term" child, 4 : 1 at five years of age, and 2 : 1 in the adult. At birth the vertical diameters of the maxillæ and the nasal fossæ are small. Added to these the alveolar processes, owing to the rudimentary condition of the teeth, are likewise small. It is frequently stated that the increase of the facial diameters after birth is in a measure due to the pneumatization of the maxillæ, ethmoid, sphenoid and frontal bones by the related paranasal sinuses. While it is true that facial increase is associated with the development of the nasal sinuses, the writer is strongly of the opinion that it is erroneous to think of the paranasal sinuses as forcing the face parts to develop or that the development of the sinuses is delayed until other parts have grown sufficiently to permit of their expansion. The writer believes that developmental processes go on hand in hand and that when a certain time is reached a structure

will normally have attained proportions for that period regardless of related parts.

The Epithelium of the Primitive Nasal Fossæ

The Olfactory Nerves.—During the third or fourth week of embryonic life the lining of the primitive nasal fossæ undergoes histogenic changes; indeed, not unlike those seen in the wall of the neural tube. The undifferentiated epithelium invaginated from the surface in the formation of the olfactory fossæ undergoes proliferation and in addition to the ordinary epithelial cells of the early fossæ forms neuroblasts. The latter become bipolar, forming short peripheral and longer central processes—the olfactory nerves. Most of the cell bodies of the neuroblasts remain permanently in the nasal epithelium, the central processes grow toward and ultimately into the olfactory bulb of the brain, while the peripheral processes project to the free surface of the epithelium. Some of the neuroblasts wander somewhat and are later found along the course of the olfactory nerves. Mihalkovics found that at first all portions of the epithelium of the nasal fossæ contain olfactory elements and connections. Be that as it may, all connections with the olfactory nerves are lost save in the upper part of the fossæ (page 261). The non-olfactory portions of the fossæ assume the rôle merely of respiratory passages. At a subsequent stage (third month) the cartilaginous cribriform plate of the ethmoid is formed around the olfactory nerve fibers and the olfactory bulb is placed on the cranial side. Ultimately (seventh or eighth month) the cribriform plate ossifies and permanent foramina for these nerves are formed.

The Nasal Glands.—The glands of the human nose develop in the third month of fetal life as solid cords and mature after birth.

The Vomeronasal Organ (Jacobsonii).—The vomeronasal organ (Jacobsonii) is a rudimentary epithelial structure in man and reaches its maximum development in the fetus at approximately the twentieth week, and at this time, according to Kallius, receives twigs from the olfactory nerves. Embryologically it appears at the caudal or stomodœal end of the olfactory pit as a blindly-ending mucous-membrane sac (Fig. 9). After the caudal closure of the olfactory pit and separation of the latter from the mouth cavity, the pocket-like vomeronasal organ is located in the nasal septum slightly above the orifice of the nasopalatine canal. It now assumes the form of a narrow duct, more or less oval in transection and courses longitudinally in the septal tissue. At ten weeks of embryonal life one finds the organ bilaterally present with an approximate depth of 0.48 mm. After this it varies considerably. Complete degeneration in

early fetal life may ensue. On the other hand, one frequently finds the vomeronasal organ in adult man. Special supporting cartilages are not developed for the organ in man. It is supplied by nerve fibers which arise from cells in its own epithelium (apparently not in adult man), also by the nervus terminalis, branches of the trigeminal nerve, and, according to Read, by a branch of the olfactory nerve, at least at the time of birth (see page 270).

The Embryonic External Nose

The frontal process, one of the cranial trabeculæ, early divides into a medial frontal process and into two lateral frontal processes. As stated elsewhere (page 4) this division is initially due to the invagination (sinking in) of the surface epithelium in the formation of the early nasal or olfactory pits. The lateral frontal processes are in reality the lateral nasal processes. Moreover, the middle frontal process undergoes secondary differentiation into the right and left medial nasal processes. The maxillary processes then grow ventromedially and fuse with the medial nasal processes, the medial and lateral nasal processes fuse at the caudal border of the nasal pits, and the lateral nasal and maxillary processes fuse along the line of the naso-optic furrow. By these several fusions of embryologic processes the upper border of the primitive mouth cavity is formed by the medial nasal and the maxillary processes, and the ever deepening nasal fossæ receive definite walls or boundaries.

The buccónasal membranes now rupture and the primitive palate is established, and with it the medial frontal process narrows and the previously widely separated nasal fossæ are brought close together. Between the buccalward-projecting medial nasal processes is a depressed area which His[1] named the infranasal area, and cephalic to the latter and caudal to the head prominence caused by the growing cerebral hemispheres is the triangular area of His. The indefinite area between the triangular and infranasal areas later takes form and gives rise to the border and tip of the nose. The triangular area becomes the dorsum of the nose and the infranasal area is modified to become the philtrum of the upper lip and the nasal septum between the nares. The combined medial nasal processes extend, of course, dorsad as the intermaxillary mass.

The external nose does not acquire its definite individual form until after birth; indeed, the form and racial characteristics are delayed until after puberty. However, by the end of the second month of embryologic life, the external nose is fairly well defined as a broad, flat organ and

[1] Anatomie menschlicher Embryonen, Leipsig, 1885.

is limited from the forehead by an arched groove. The dorsum of the nose is especially active in taking form early and later in fetal life the nostrils assume a more caudal and horizontal position and the median portion of the dorsum grows caudally and ventrally to become the tip of the nose. In the newborn the bridge of the nose is low and the nose proper relatively broad and stumpy.

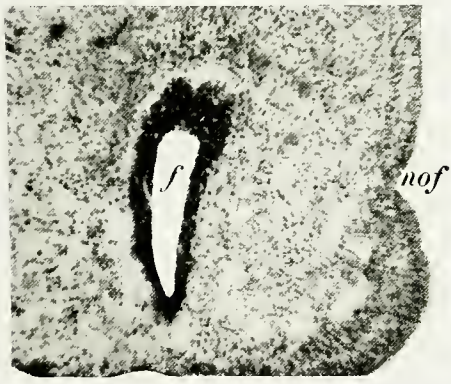

FIG. 44.

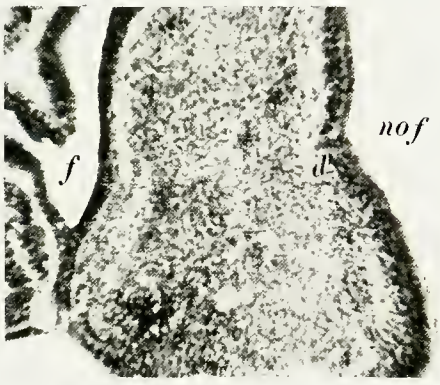

FIG. 45.

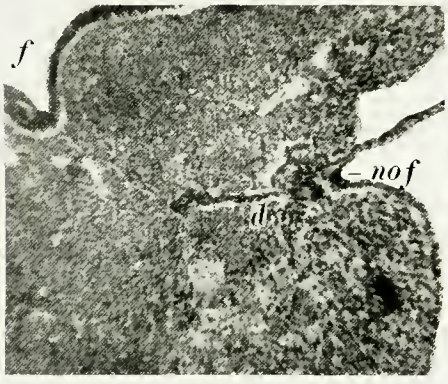

FIG. 46.

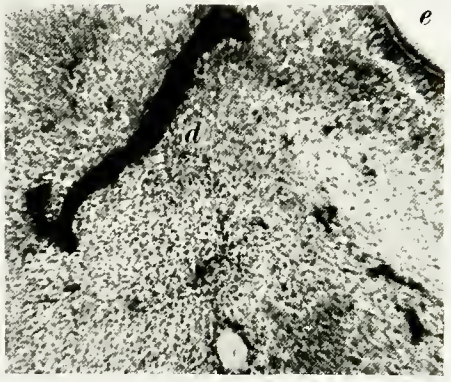

FIG. 47.

FIGS. 44–47.—Photomicrographs of frontal sections of the heads of human embryos showing several stages in the development of the nasolacrimal passageways: Fig. 44 aged 33 days; Fig. 45 aged 35 days; Fig. 46 aged 36 days; Fig. 47 aged 43 days. ×7. (*After J. P. S.*)

nof = Remains of naso-optic furrow; *f* = nasal fossa; *e* = eye; *d* = different stages of the rudiment or anlage of the nasolacrimal passageways.

THE NASOLACRIMAL PASSAGEWAYS

The lacrimal sac (saccus lacrimalis) and the nasolacrimal duct (ductus nasolacrimalis) are in no way connected with the sense of smell. However, they are so closely related to the nasal fossa that a note concerning their embryology is warranted in this connection. The following sum-

mary from a previous publication (see Schaeffer, American Journal of Anatomy, Vol. 13, No. 1, 1912) on the genesis of the nasolacrimal passageways will suffice:

1. The strand of thickened epithelium—the rudiment or anlage of the nasolacrimal passageways—along the floor of the rudimentary naso-optic fissure becomes entirely separated from the surface, and for some time is wholly surrounded by mesenchymal tissue, Figs. 44 to 48.

2. The strand or cord of epithelial cells thus isolated from the surface is for some time without a lumen.

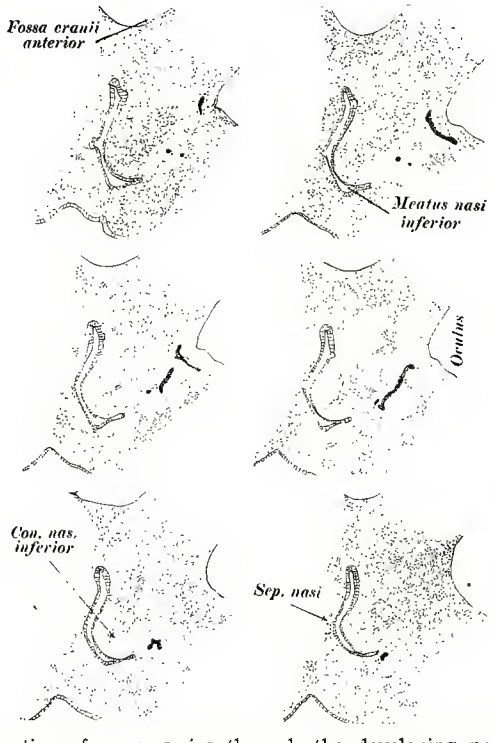

FIG. 48.—Selected sections from a series through the developing nasolacrimal passageways (human embryo aged from 43 to 45 days). Nowhere is the rudiment or anlage of the nasolacrimal passageways in connection with the surface epithelium. The "passageways" are solid cords of epithelial cells at this time and are indicated in deep black. × 14. (*After J. P. S.*)

3. From the mother cord of cells both lacrimal ducts and the nasal end of the nasolacrimal duct grow as sprouts. The cephalic portion of the lacrimal sac also grows as a sprout from the mother cord.

4. Considerable variation occurs in the development of the lacrimal ducts, *i.e.*, as to number, time, and degree of development.

5. The lumina of the several portions of the nasolacrimal passageways are established in an irregular manner. The ocular end of the mother

cord is the first to establish a lumen. The point of coalescence between the nasal end of the cord and the mucous membrane of the inferior nasal meatus is the last to become patent—the lumen here is established approximately at "term" or even later. The horizontal portions of the lacrimal ducts establish lumina before the vertical portions.

The divers types of ostia nasolacrimalia found in the adult are in accord with the potentialities of lumen formation at the point of fusion of the solid epithelial nasolacrimal duct with the mucous membrane of the inferior nasal meatus. The place and degree of fusion vary considerably (Figs. 51, 52 *D;* also Schaeffer, American Journal of Anatomy, Vol. 13, No. 2, 1912), thus leading to variously located ostia, single and multiple ostia, unguarded and "valved" ostia.

The relations of the nasolacrimal ducts to the nasal fossæ and the paranasal sinuses and the communication of the ducts with the inferior nasal meatuses are discussed under the proper headings in connection with the adult anatomy (pages 252–253 and Figs. 173 and 177).

Congenital Defects of the Nose

The manner in which embryologic epithelially-covered mesenchymal processes unite in the formation of the early nose and roof of the mouth is illustrated in Fig. 3 in which the medial nasal and the maxillary processes are undergoing fusion. At places the epithelial "union" is entirely lost and the mesoblastic tissue bridges or heals over the previous embryologic fissure; *e.g.*, the mesoblast of the maxillary process is confluent with that of the medial nasal process. These photographic representations of sections from a human embryo illustrate the manner in which all of the fissures about the nose and mouth are obliterated. If for some reason fusion of the several processes is too long delayed, continued growth of the several elements bordering the fissures causes them to separate and once the breach in their continuity is established union cannot take place subsequently. Lack of fusion and separation of the several processes leads to the malformations known as cleft palate and harelip. Divers degrees of these malformations occur both unilaterally and bilaterally.

In harelip the cleft or defect may appear laterally between the medial part of the lip formed by the medial nasal processes and the lateral part of the lip formed by the maxillary process (lateral harelip). Should the medial nasal and lateral nasal processes fail to unite at the floor of the naris (nostril) the lateral harelip would be continued into and be confluent

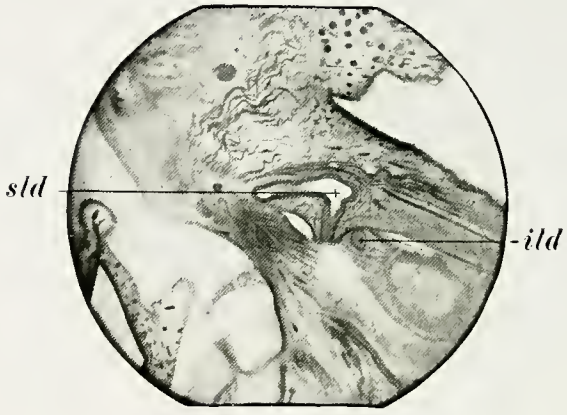

FIG. 49.

FIG. 50.

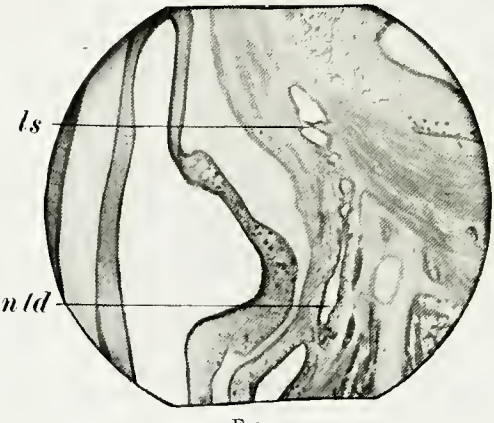

FIG. 51.

FIGS. 49–51.—Frontal sections through the nasolacrimal passageways of a human embryo aged 107 days. Note that both lacrimal ducts (Fig. 49) are in contact and fused with the epidermis in the region of the free borders of the eyelids, but that the ducts have not established lumina at all points. The remaining portions of the passageways are irregularly patent throughout, save that the connection with the inferior nasal meatus is not established at this time (Fig. 51). (*After J. P. S.*)

sld = superior lacrimal duct; *ild* = inferior lacrimal duct; *cld* = common lacrimal duct; *ls* = lacrimal sac; *nld* = nasolacrimal duct. ×11.

with the nasal vestibule. Rarely a cleft is found in man in the median line of the upper lip due to a lack of superficial union of the right and left medial nasal processes (median harelip)—a condition always present in the upper lip of the hare.

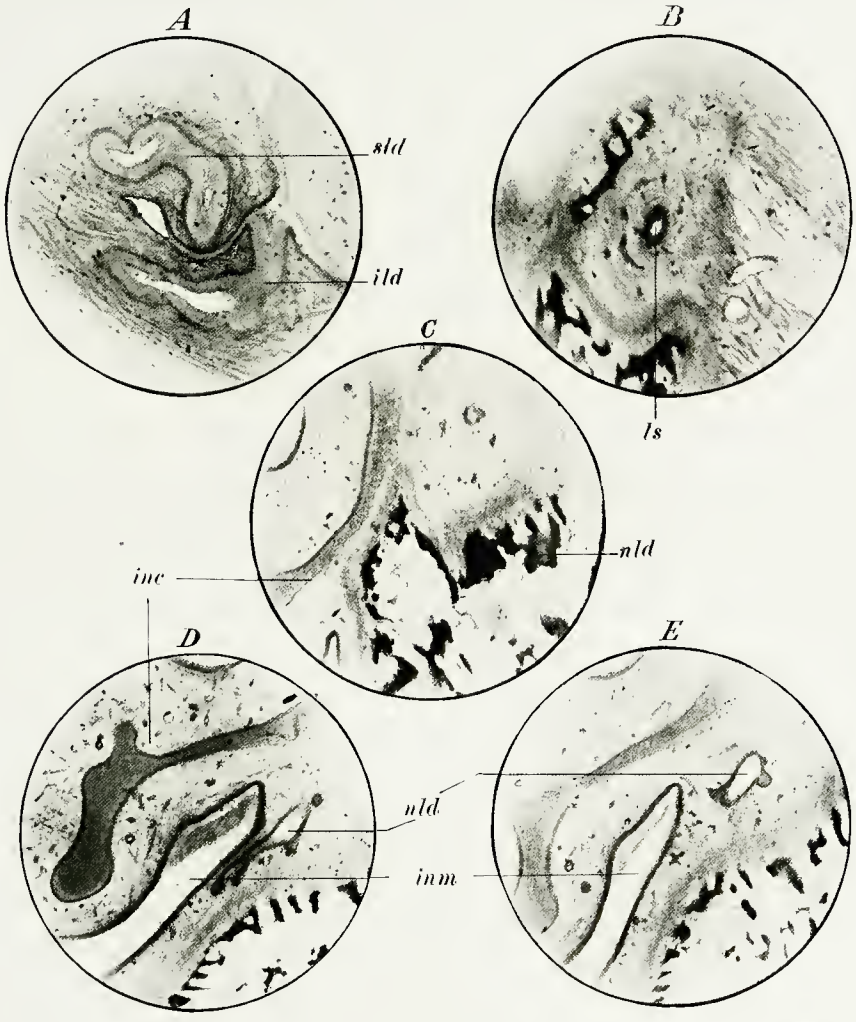

FIG. 52.—Photomicrographs of frontal sections through the nasolacrimal passageways of a human embryo aged 128 days. Note the solid portions of the lacrimal ducts in Fig. *A*. In Fig. *B*, we have a patent section (*ls*) of the ocular end of the nasolacrimal duct and in Fig. *C*, a section of the mid-portion of the nasolacrimal duct still solid (*nld*). Note the well established lumen (*nld*) at the nasal end of the nasolacrimal duct in Figs. *D* and *E*. Note how extensive the contact point between the nasolacrimal duct and the inferior nasal meatus will be (Fig. *D*). *sld* = superior lacrimal duct; *ild* = inferior lacrimal duct; *ls* = lacrimal sac; *nld* = nasolacrimal duct; *inc* = inferior nasal concha; *inm* = inferior nasal meatus. ×19. (*After J. P. S.*)

Normally the sockets of all four incisor teeth are formed by the premaxillæ. However, in some cases of cleft palate the sockets of the right

and left lateral incisors are attached to the right and left maxillæ proper, respectively—the central incisors alone appearing on the premaxillæ. Indeed, the lateral incisor may occasionally under normal conditions have its socket in the maxilla. Albrecht erroneously supposed that each premaxilla was made up of two osseous elements, a lateral and a medial, and that in cleft palate the fissure might lie between these supposed elements of the premaxillary or between the premaxillary and the maxillary processes. While it is true that clefts do occur in both of these positions it is, however, obvious that cleft palate is not due to a failure of osseous centers to coalesce, but to a *non-union of pre-osseous embryologic masses.* Each premaxilla has a single ossification center as pointed out by Mall.

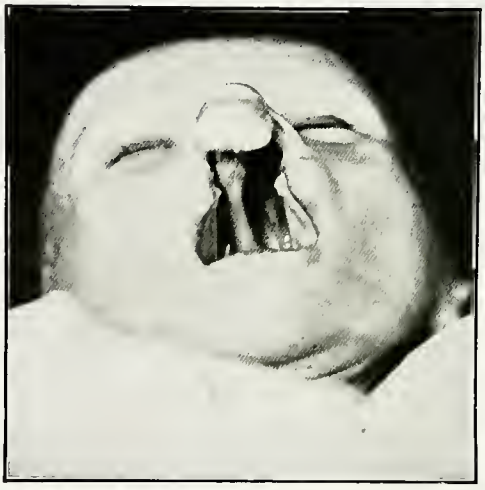

FIG. 53.—Infant with complete harelip on left, partial on right, and cleft palate. Note the protrusion of premaxillary bones and the complete isolation of the vomer from both palatal plates. (*After Brophy.*)

Keith finds that the partial suture "which may divide the palatal part of the premaxilla is due not to two centers of ossification, but to the formation of the palatal part by two processes (pre-osseous), one corresonpding to the middle incisor socket, the other to the lateral incisor." It is important to keep in mind that the rudiment of the lateral incisor tooth is formed at the point of coalescence of the medial nasal and the maxillary processes and in the event that these processes fail to merge that the lateral incisor tooth rudiment may be carried "away" by either the maxillary or premaxillary elements in their further and subsequent separation incident to growth. This accounts for the variability in the location of the lateral incisor tooth in cleft palate—now in the maxilla, again in the premaxilla. Keith's suggestion that the palatal portion of the premaxilla is at times in

the pre-osseous stage made up of two processes, one corresponding to the medial incisor rudiment, the other to the lateral incisor, explains the occasional cleft in the newborn between the medial and lateral incisors. The fact that the lateral incisor rudiment may be carried "away" by the maxillary process must not be forgotten in this connection.

The cleft between the maxillary process and the medial nasal process may not involve only the lip and the alveolar process, but may extend dorsad toward or to the incisive canal. Moreover, it may continue dorsad in the mid-sagittal plane in the formation of various degrees of partial cleft palate or if carried to the end of the soft palate to complete cleft palate. The same processes may be operative bilaterally, fissuring both sides of the upper lip and the alveolar processes and the forward portion of the palate as far as the incisive foramina, and if occurring simultaneously

FIG. 54.—Infant three months old with complete double harelip. (*After Brophy.*)

with complete fissuration in the mid-saggital plane of the remaining portion of the hard and soft palates, a tripartite palate results. If, on the other hand, the fissuration is complete dorsally but unilateral ventrally, the bipartite palate results. As stated previously, many intermediate degrees of cleft palate occur, Figs. 53 and 54.

The buccal border of the nasal septum may or may not be adherent to one of the lateral halves of a cleft palate. If attached to a lateral half one of the nasal fossæ would be closed in caudally and the other in free communication with the mouth cavity. In the event that the septum projects freely in the roof of the buccal cavity, both nasal fossæ are in wide communication with the mouth cavity. Obviously, the degree of naso-buccal communication is dependent upon the degree of cleft palate.

It is not the province in this connection to enter into the details of cleft palate and harelip. The reader is referred to an extensive literature

on the subject, especially to the works of Keith,[1] Inouye,[2] His,[3] Brophy,[4] Gaupp[5] and Schorr.[6]

Congenital absence of the external nose is a very rare anomaly. Maisonneuve reports the case of an individual in which the projecting portion of the nose was represented by an even surface, perforated by two minute apertures three millimeters apart. Roberts reports the case of an infant in which there was no evidence of the external nose whatsoever, even the narial apertures were entirely wanting. Moreover, the condition was associated with harelip and a tripartite palate.

Exaggerations in volume of the projecting nose are not infrequent. It is stated that one Thomas Wedders had a nose between seven and eight

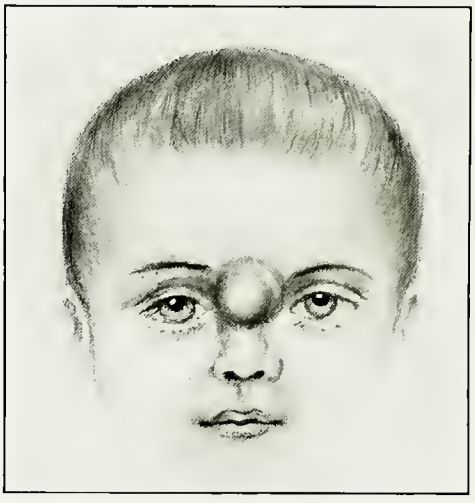

FIG. 55.—Congenital dermoid in a female child aged 3 years. The tumor was noticed directly after birth.

inches long and was exhibited in Yorkshire early in the last century. Under-sized external noses are less frequent. The writer, however, recently observed a nose which was markedly under-sized, the bridge being but little elevated above the plane of the face. Departures from what may be considered normally sized external noses are in many cases merely individual, family, and racial characteristics and must not be considered malformations. Pathological formations must not be confused with congenitally large noses.

[1] British Medical Journal, August, 1909.
[2] Anat. Hefte, Vols. 45 and 46, 1912.
[3] Anatomie menschlicher Embryonen, Leipsig, 1885.
[4] Oral Surgery, Philadelphia, 1915.
[5] Anat. Hefte, Vol. 42, 1911.
[6] Anat. Hefte, Vol. 36, 1908.

Keith cites the case of Kirchmayer in which one olfactory pit and the lateral nasal process formed a free polypoid body, and another in which the condition of cyclops with both nasal fossæ enclosed in a proboscis was encountered.

Congenital occlusion of the nares due to epithelial proliferation with subsequent organization was previously referred to (page 10). Similar occlusions may block the choanæ. However, at times the congenital occlusion of the choanæ is an osseous one. One readily sees how ossification may block the choanæ if the embryology of the region is clearly kept in mind.

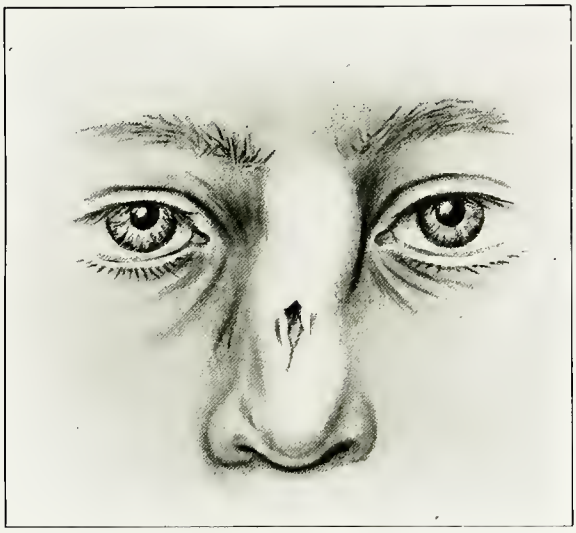

FIG. 56.—Congenital dermoid fistula in a girl aged 21 years. On pressure of the tumor sebaceous matter was discharged from the tunnel-like opening on the dorsum nasi. (*Adapted from Krieg.*)

Flattened or depressed alæ usually accompany harelip, while crooked noses often accompany traumatic or spontaneous deviations of the nasal septum.

Congenital dermoids on the bridge of the nose are not unknown. A very common place for them is on a level with the canthi (Fig. 55). Moreover, fistulæ of congenital dermoids have been observed at various levels on the dorsum nasi, Fig. 56.

II—THE DEFINITIVE NOSE

CHAPTER II

THE DEFINITIVE NOSE

In this chapter will be discussed the anatomy of the fully developed or definitive nose. Even after puberty certain important and fundamental developmental changes take place in the nose and these will be referred to at their proper places. It is not deemed profitable nor essential in this connection to describe the detailed osteology of each individual bone that participates in the make-up of the osseous cage of the nasal cavity. Suffice it in subsequent paragraphs to discuss certain of the more important anatomical points of individual bones and more especially to treat the osseous boundaries of the nasal fossæ as a whole. The paranasal (accessory) sinuses will be dealt with in subsequent and separate chapters.

The nose consists of two conspicuous portions—the external nose (nasus externus) and the internal nose (nasus internus). The latter, more strictly the nasal cavity, is divided into two fossæ or chambers (fossæ nasales) by the nasal septum (septum nasi). Moreover, the nasal fossæ are extended by the nasal meatuses (meatus nasi) and the paranasal (accessory) sinuses (sinus paranasales). The nasal conchæ (conchæ nasales) configure the lateral walls of the nasal cavity and further increase the surface area of the nasal mucosa.

The External Nose

Individual and family variations of the external nose (nasus externus) are extremely common and of little importance. However, entirely apart from individual variation, the human external nose is readily grouped into several more or less distinct anatomic types. The root of the nose forms with the tissues of the forehead a variable obtuse angle. Some sort of a frontonasal angle with a straight dorsum nasi may be taken as the ground type of nose (straight type of nose) from which there are, however, definite anatomic departures. If the frontonasal angle is wanting, *e.g.*, the dorsum of the nose forms with the tissues of the forehead a straight angle, the Grecian type of nose is produced. The dorsum of the nose is not infrequently convex, giving rise to the nasus aduncus or aquiline type of nose. The nasus avicularis or Roman nose and the Jewish nose are variations of the aquiline type due to modification of the angle on the dorsum nasi. In the Jewish nose the tip is depressed,

with a resultant general forward curvature of the entire dorsum nasi. The Roman nose, on the other hand, presents a rather acute angle at the point of confluence of the bony and cartilaginous portions of the dorsum nasi and a more prominent nasal tip. Another type of nose is encountered when the dorsum nasi is depressed (concavity). This leads to a relatively prominent nasal tip and gives rise to the pug or saddle type of nose (the nasus simus or nasus nasicornis, the nez retroussé of the French). Such an individual is said to be flat-nosed, snub-nosed. Topinard's nasal types are: (1) the curved, (2) the straight, (3) the depressed or stumpy, (4) the Roman, (5) the Jewish or aquiline, Figs. 57–61.

Topinard and others have shown that there is one kind of variation which is of considerable anthropologic importance, *e.g.*, the degree or lateral expansion of the nares (anterior nares) as compared with the total length of the nose. This relationship is expressed by the cephalometric

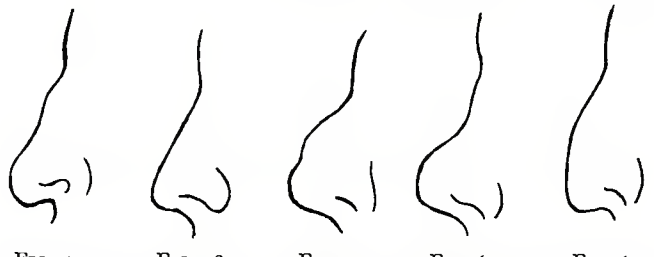

FIG. 57. FIG. 58. FIG. 59. FIG. 60. FIG. 61.

FIGS. 57–61.—Topinard's nasal types. Fig. 57, Roman; Fig. 58, straight; Fig. 59, curved; Fig. 60, depressed or stumpy; Fig. 61, Jewish or aquiline.

nasal index—$\frac{\text{greatest breath} \times 100}{\text{greatest length}}$. It is found that in the white races of mankind the nasal index is below 70 (leptorrhines), giving the long, high nose; in the black races (African, Australasian) it is 85 and upward (platyrrhines), giving the short, low nose; and in the red and yellow races (Asiatic, Eskimos, American Indians) it is from 70 to 85 (mesorrhines), giving a type intermediate between the other two. The nasal index is sometimes determined by considering the length of the nose as extending from the frontonasal suture to the anterior nasal spine. Then the leptorrhine index is below 48, the mesorrhine from 48 to 55, and the platyrrhine above 55. The latter index obviously does not utilize the greatest length of the nose.

The external nose forms a conspicuous triangular pyramid that projects from a point below the glabella, ventral- and caudalward to terminate in a free angle. The cephalic end is referred to as the root (radix nasi) and the free angle as the point or apex (apex nasi). Connecting the two extremities in the form of a rounded median ridge is the

dorsum nasi. The cephalic part of the dorsum is supported by the nasal bones and is here called the bridge of the nose. The lateral surfaces of the nose (partes laterales nasi) extend from the dorsum to become confluent with the tissues of the face proper (nasofacial angles) and distally they end in rounded eminences, the alæ nasi, which form with the upper lip the nasolabial sulci. The base of the nasal pyramid is pierced by two openings, the nostrils or nares (anterior nares). The entire external nose is supported by a bony and cartilaginous framework and covered by skin and muscles (Fig. 68).

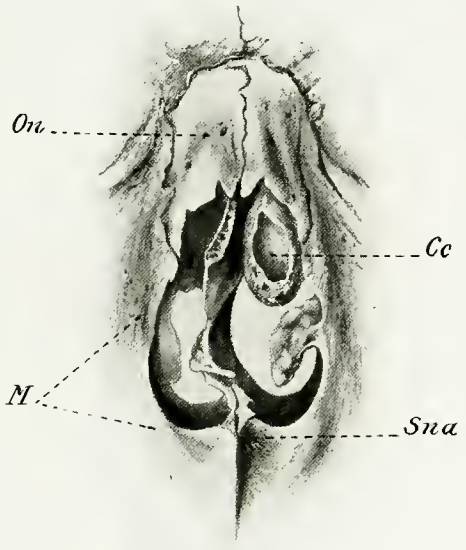

FIG. 62.—The osseous pyriform aperture of the nasal cavity. Note the conchal cell (ethmoidal cell) in the concha nasalis media.

On = os nasale; *M* = maxilla; *Cc* = conchal cell; *Sna* = spina nasalis anterior.

The Bones of the External Nose.—The bones that participate in giving shape and support to the external nose are the nasal bones (the nasal bridge), the maxillæ, and the nasal part (pars nasalis) of the frontal bone. The latter occupies the ventral portion of the ethmoidal notch and projects beneath the nasal bones and the frontal processes of the maxillæ, thus lending support to the bridge of the nose. The arch-like construction in the coronal plane of the nasal bones and the frontal processes of the maxillæ is in itself reasonably strong. Moreover, the elements that enter into the composition of the nasal septum act as a unit in supporing the entire dorsum of the nose.

The paired *nasal bone* (os nasale) is developed in membrane (accord-

ing to Perna and Livini, in membrane and cartilage, see page 42 on the ossification of the nasal bone). The adult bone is narrow and robust above, but becomes thinner and wider at its lower extremity. The serrated cephalic border (margo frontalis) articulates with the medial portion of the nasal margin (margo nasalis) of the frontal bone and the notched caudal border in the dried skull is free and in the recent state gives attachment to the lateral nasal cartilage. The longer lateral border (margo maxillaris) articulates with the frontal process (processus frontalis) of the maxilla. The median border (margo nasalis) is robust above and less so below and articulates with its fellow of the opposite side in the formation of the internasal suture. Entally the two nasal bones conjointly form a crest (crista nasalis) to meet with the frontal spine (spina frontalis)

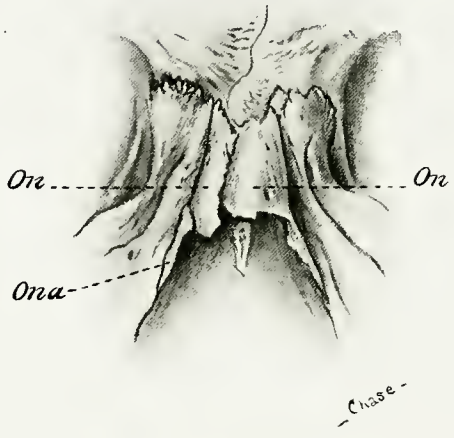

FIG. 63.—A drawing of a specimen showing asymmetrical nasal bones; also an accessory nasal bone.
On = os nasale; *Ona* = os nasale accessoria.

of the frontal bone, the perpendicular plate (lamina perpendicularis) of the ethmoid bone, and the septal cartilage (cartilago septi nasi). The ental or nasal surface at its cephalic end articulates with the frontal bone, elsewhere it is concave and smooth and is invested by the nasal mucosa. This surface is grooved—the *sulcus ethmoidalis*, for the nasal branch of the naso-ciliary nerve. The ectal or facial surface is concave from above downward for a considerable distance, caudally it is convex (Figs. 62 and 66).

The foregoing description of the normal nasal bones is deemed advisable since departures from the normal are not infrequent. In X-ray photographs and in visual and manual examinations of the bridge of the nose due consideration must be given to variations in the osteology of the nasal bridge lest faulty interpretations be given.

The shape and measurements of the nasal bones vary greatly in different individuals. Generally speaking, they are relatively large and prominent in the white races and small and less prominent (flat) in the

FIG. 64.—A drawing of a specimen showing complete agenesis or absence of the nasal bones, also a detached osseous element of the frontal bone (*Of*). Particularly note that the nasal bones are replaced by the nasal or frontal processes (*PfM*) of the maxillæ.

dark and yellow races. Ape-like the two nasal bones in man at times fuse by obliteration of the internasal suture. The bones are frequently variously reduced in size and altered in shape by encroachment of the

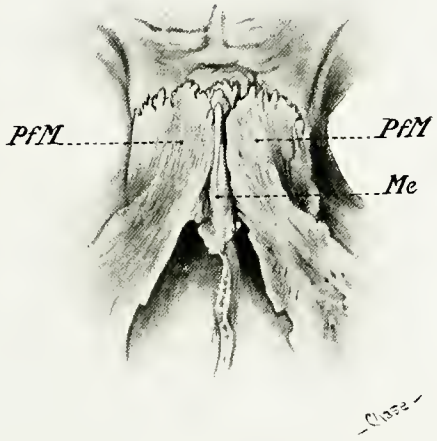

FIG. 65.—A drawing of a specimen showing complete agenesis or absence of the nasal bones but in which the mesethmoid (*Me*), e.g., the perpendicular lamina (vertical plate) of the ethmoid bone, comes to the surface between the frontal processes (*PfM*) of the maxillæ which replace the nasal bones.

frontal processes of the maxillæ. Indeed, the latter may reduce the nasal bones to a mere mid-sagittal ridge or replace them altogether by articulat-

ing with each other in the formation of the nasal bridge (like the catarrhine monkeys). The author has in his collection a human skull in which both nasal bones are absent, the perpendicular plate of the ethmoid bone coming to the surface in the mid-sagittal plane between the frontal processes of the maxillæ (often seen in the orang). Medial projections of the frontal bone rarely replace the nasals. Furthermore, each nasal bone may appear as several pieces or may be divided by a vertical fissure. Additional ossicles are occasionally found in the line of the internasal suture or between the nasal and neighboring bones. The subjacent cartilage of the nasal capsule may ossify at places and form minute plates of bone beneath the adult nasals proper. Again, the nasal bones are elongated and bound the pyriform nasal aperture along its lateral margins. Rarely the nasal bones are absent and the place filled in by membrane (Figs. 63, 64 and 65).

In the skeleton the nasal fossæ open externally on the face region by more or less asymmetrical pyriform apertures which conjointly form an inverted, cordiform-shaped opening at a level distinctly above the nares of the nose (in the recent state). The floor of the wider aperture is usually at a somewhat higher plane than that of the narrower one. The cordiform aperture is bounded cephalically by the free border of the nasal bones and elsewhere by the maxillæ. As stated elsewhere, the nasals at times project caudally along the lateral walls of the cordiform aperture. In the mid-sagittal plane, and projecting ventrad from the floor of the aperture, is the prominent anterior nasal spine, usually directed toward the widest aperture (Fig. 161).

Usually the floor of the aperture is dull and rounded and directly continuous with its sharp lateral border. Occasionally, however, in the adult and nearly always in the infant and low races, extending from the lateral margin of the incisor crest and anterior nasal spine are two bony ridges, the ventral one confluent with the ventral surface of the maxilla and the dorsal one coursing inside the nose ventral to the inferior turbinated crest. These two ridges enclose a distinct depression—the fossa prenasalis, on the face, immediately below the bony nasal aperture. However, as a rule the identity of the two lines is lost by fusion in the adult. Variations are encountered.

The Cartilages of the External Nose.—As stated above, the pyriform aperture (apertura pyriformis) of the dried and prepared skull is bounded by the free borders of the nasal bones and the maxillæ. In the recent state this aperture is enclosed and continued to the nares or nostrils (anterior nares) by the nasal cartilages and contiguous tissues. Four major carti-

FIG. 66.—An adult skull with the individual bones separated. Note the metopic suture and that the frontal sinuses do not extend beyond the midline, the usual anatomy in such cases. The maxillary and frontal sinuses are shown in dotted outline.

lages (cartilagines majores) participate in the formation of the framework of the external nose. Moreover, a variable number of minor or accessory cartilages (cartilagines minores) are usually found. The major cartilages are the paired lateral and greater alar cartilages. The accessory elements are the accessory alar cartilages and the sesamoid cartilages. Although the unpaired septal cartilage and the vomeronasal cartilages of Jacobson likewise assist directly or indirectly in the support of the external nose they will be discussed in connection with the nasal septum.

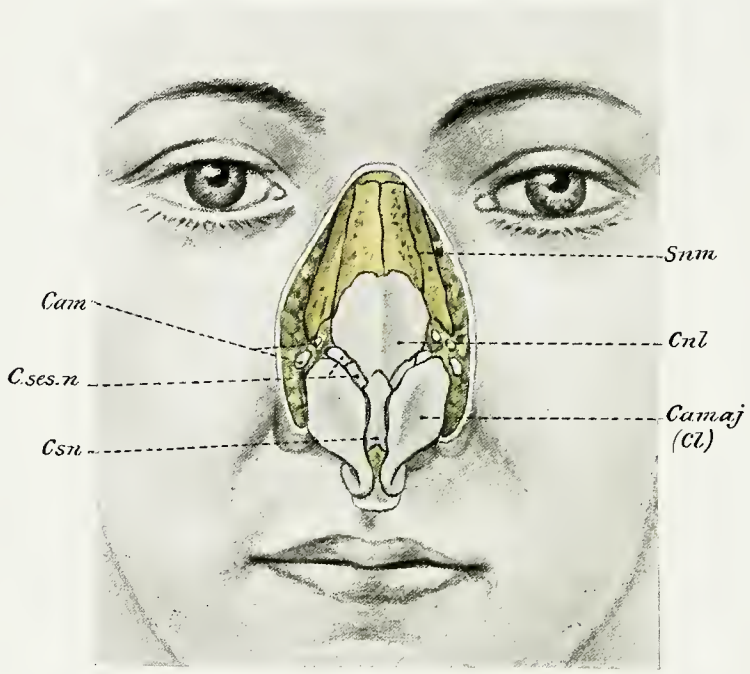

FIG. 67.—The cartilages of the external nose as displayed (frontal view) after the removal of the skin and muscles.

Cam = cartilagines alares minores; *C. ses. n* = cartilagines sesamoideæ nasi; *Csn* = cartilago septi nasi; *Cnl* = cartilago nasi lateralis; *Camaj* (*Cl*) = cartilago alaris major (crus laterale). *Snm* = sutura nasomaxillaris.

The division of the major nasal cartilages is, in a sense, arbitrary and unwarranted. As mentioned previously, in connection with the embryology and morphology of the cartilaginous nasal capsule, the three major nasal cartilages (two paired, one unpaired) constitute one piece (cartilagino mediana nasi). The lateral nasal cartilages and the septal cartilage remain connected in the adult, while the greater alar cartilages become disconnected and appear as independent elements.

The greater alar cartilage (cartilago alaris major) partially encircles the ventral part of the naris (nostril), assists in keeping the naris and

vestibule open, and with its fellow gives shape to the base of the nose. The cartilage consists of two crura—one *medial* (crus mediale) and one *lateral* (crus laterale), in relation to the naris. The crura are continuous with each other at the apex of the nose, giving the latter a rounded contour. The interval between the lateral crus of the cartilage and the maxilla is filled in by a strong sheet of fibrous tissue in which are embedded the lesser alar cartilages. At times the lateral crus is prolonged dorsolaterally so as to replace the lesser cartilages. Moreover, the lateral crus is bound to the lateral cartilage by a fibrous membrane and to the caudoventral

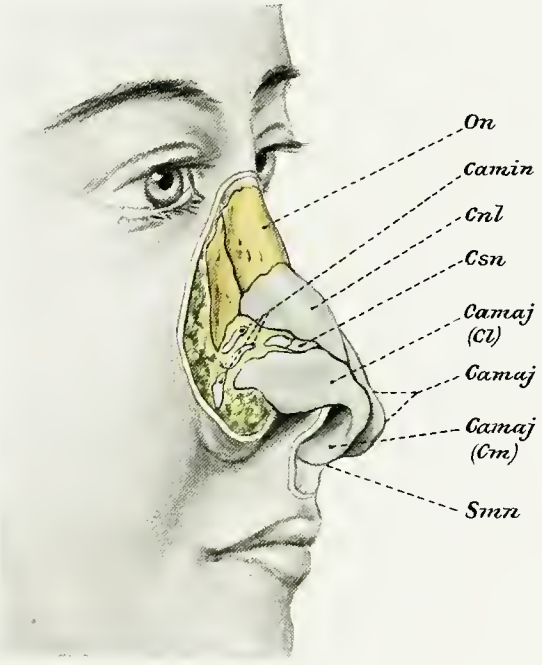

FIG. 68.—The cartilage of the external nose as displayed (profile view) after the removal of the skin and muscles.

On = os nasale; *Camin* = cartilagines alares minores; *Cnl* = cartilago nasi lateralis; *Csn* = cartilagines sesamoideæ nasi; *Camaj* (*Cl*) = cartilago alaris major (crus laterale); *Camaj* = cartilago alaris major; *Camaj* (*Cm*) = cartilago alaris major (crus mediale); *Smn* = septum mobile nasi.

part of the cartilaginous septum. Toward the median plane the lateral crus is curved backward to form the medial crus. Here the latter bounds a deep median groove, meets with its fellow of the opposite side and extends dorsalward in the columna nasi caudal to the cartilage of the septum. The medial crus ends dorsally in a free, out-turned border (Figs. 67, 68).

The lateral nasal cartilage (cartilago nasi lateralis) is a flattened, triangular plate located in the middle part of the lateral surface of the

projecting portion of the nose, immediately distal to the free border of the nasal bone. One surface looks toward the nasal cavity and the other ventrolaterally toward the external face. The dorsal edge or border of the cartilage is thin and is attached to the maxilla and to the nasal bone; its ventral border is thick and above directly continuous with the cartilage of the septum. As stated before, its lower edge is attached by fibrous tissue to the upper edge of the lateral crus of the greater alar cartilage (Figs. 67 and 68).

The lesser alar cartilages (cartilagines alares minores) are small and variable in number. They are found bilaterally embedded in the strong fibrous tissue of the wing of the nose in the interval between the lateral crus of the greater alar cartilage and the maxilla. Sometimes a dorsolateral extension of the lateral crus of the greater alar cartilage replaces the lesser alar cartilages in part or in whole (Fig. 67).

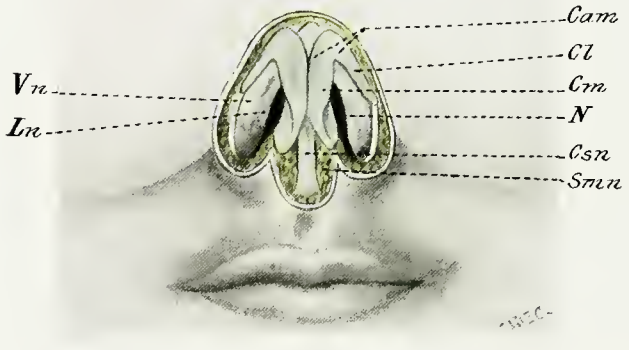

FIG. 69.—The cartilages of the nose as related to the nares (anterior nares) or nostrils. *Cam* = cartilago alaris major (*Cl* = crus laterale, *Cm* = crus mediale); *Csn* = cartilago septi nasi; *Smn* = septum mobile nasi (columna nasi); *Vn* = vestibulum nasi; *Ln* = limen nasi, limen vestibuli; *N* = naris.

The sesamoid nasal cartilages (cartilagines sesamoideæ) of the nose when present are located in the interval between the lateral nasal and septal cartilages medially and the lateral crus of the greater alar cartilage laterally. They are very small and vary in number from one to three or more (Fig. 67).

The Muscles of the External Nose.—The position of the alæ of the nose can be altered by the attached muscles and facial expression modified thereby. The pars transversa of the nasalis (compressor nares); the caput angulare of the quadratus labii superioris (levator labii superioris alæque nasi); and the dilatores naris, anterior and posterior, elevate and dilate the

naris (nostril). The pars alaris of the nasalis (depressor alæ nasi) and the depressor septi nasi depress and contract the naris. Poirier and Duchenne found that the pars transversa and the caput angulare act conjointly in drawing laterally and cephalically the lateral margin of the ala of the nose, the position of the nostril expressing sensuality. When the pars transversa acts with the pars alaris it may constrict the naris. Expressions of pain and anger are brought about by the pars alaris and the depressor septi nasi. The reader is referred to more extensive treatises on facial expression and anthropology for details.

In conclusion the author wishes to urge the great cosmetic importance of the external nose and that a knowledge of the types of face and nose, of the osseous and cartilaginous nasal framework, of the nasal muscles and the blood and nerve supply is essential to those dealing with deformities and injuries of the organ; especially so since plastic surgery of the face is now very much in the foreground.

The Internal Nose

The anatomy of the internal nose (nasus internus) is that of the nasal cavity (cavum nasi) and ancillary structures. The general nasal cavity is divided by a median septum (septum nasi) into two more or less symmetrical halves—the nasal fossæ (fossæ nasales). Moreover, the fossæ are further divided into nasal meatuses (meatus nasi) by the nasal conchæ or turbinates (conchæ nasales) and are extended into neighboring bones by the paranasal (accessory) sinuses (sinus paranasales). The fossæ communicate with the exterior through the nares (anterior nares) and with the nasopharynx dorsally through the choanæ (posterior nares). Conforming with the more specific functions, the nasal fossæ are divided into respiratory and olfactory portions, *e.g.*, pars respiratoria and pars olfactoria respectively.

There is great variation in the degree of development and complexity of the nasal fossæ and contained structures and the olfactory lobes in mammals. This led Turner to divide them into three subdivisions: macrosmatics (rodents, carnivora, marsupials and most mammals); anosmatics (certain cetacea—porpoise); and microsmatics (man, most primates and some cetacea).

Each nasal fossa is roughly triangular in frontal or coronal section. The narrow roof of the fossa may be considered the apex of the triangle and the wider floor the base. The median wall is usually unbroken and even and approximately vertical, meeting the floor at nearly a right angle.

The lateral wall, the hypotenuse of the triangle, is sloping and is configured by the major and minor nasal conchæ and meatuses and by the impinging paranasal sinuses. In sagittal section the contour of the nasal fossa represents a quadrangle, the cephalic side or roof of which is approximately parallel to the caudal side or floor. The ventral or anterior side of the quadrangle conforms to the profile of the external nose and forms with the caudal side or floor an acute angle at the naris. The dorsal side falls along the ventral surface of the body of the sphenoid bone, then passes through the choana (posterior naris) in front of the ostium pharyngeum of the tuba auditiva (Eustachian tube) to impinge upon the dorsum of the junction-point between the hard and soft palates. Laterally the dorsal limit of the nasal fossa is indicated by the nasal sulcus (sulcus nasalis posterior) which extends from the angle formed by the confluence of the ventral and caudal surfaces of the body of the sphenoid bone to the junction of the hard and soft palates.

There is considerable variation in the dimensions of the nasal fossæ. The type of nose and the degree of arching of the palate obviously must affect the dimensions of its chambers. The degree of development of the nasal conchæ and the size, shape and disposition of the paranasal sinuses affect the symmetry of the nasal fossæ in the same individual and in different individuals. The following may be taken as representative dimensions based upon a large series of specimens studied by the writer: The greatest sagittal diameter, measured from the most prominent part of the naris along the floor of the nasal fossa to the dorsal border of the hard palate, is 74 mm., while the extreme sagittal diameter measured along the roof of the fossa is but 35 mm. or less. The greatest height (vertical diameter) is found by dropping a perpendicular line from the ventral third of the cribriform plate of the ethmoid bone to the floor of the nasal fossa—averaging from 40 to 45 mm. The nasal fossa is a mere cleft in the coronal or frontal plane (width) along the cribriform plate (roof)—3 mm. or less. The widest part of its floor varies from 12 to 23 mm., measured at the greatest lateral expansion of the inferior nasal meatus. The width of the floor in advance of the knee of the inferior nasal concha is much reduced—4 mm. or less. It is well to remember that after the normal point of constriction is passed the inferior nasal meatus is much more roomy.

The Nares (nostrils, anterior nares).—The nares of man are remarkable on account of their position, looking as they do almost directly caudalward. The base of the nose varies considerably. Individual variations are extremely commonplace and not important. There are, however,

several anatomic types which are of anthropologic interest and importance. When the tip of the nose is depressed the transverse diameter through the alæ is great and the greatest diameter of the nares is placed horizontal, *e.g.*, in the black races. In those cases where the tip of the nose is fairly prominent, as in the white races, the transverse diameter through the alæ is lessened and the nares are nearly in the sagittal plane in the greatest diameter. The inter-alar distance is less in the red and yellow races than in the black races and the nares here occupy a halfway position between the horizontal and the sagittal planes.

The Vestibule (vestibulum nasi).—The paired vestibule may be considered an antechamber to the nasal fossa. It corresponds more or less in its extent to the cartilaginous nasal wall. The vestibule is located immediately ental to the aperture of the naris (nostril) and is supported by the medial and lateral plates of the great alar cartilage and adjacent portions of the nasal septum and integument. The extension of the vestibule into the tip of the nose is often referred to as the ventricle of the vestibule (*recessus apicis*). The deepest and lateral boundary of the vestibule is formed by the upper and arching border of the lateral plate of the great alar cartilage and the lower border of the lateral cartilage. The cartilages throw the overlying tissues into a prominent ridge, forming with the cartilages the *limen vestibuli* or the *limen nasi* (Fig. 197). At the latter the skin lining the vestibule suffers a transition into the mucous membrane lining the nasal fossa proper (see nasal mucous membrane, page 261). The skin lining the vestibule is supplied with hairs (vibrissæ)—stout and coarse immediately within the naris and short, slender and scattered elsewhere, and with sudoriferous and sebaceous glands. Both the hairs and glands are wanting near the limen nasi.

The Choanæ (posterior nares).—The definitive choanæ are the communicating passageways between the nasal fossæ and the nasopharynx (Fig. 141). The nasal meatuses and the dorsal extremities of the nasal chonchæ converge toward the dorsal apertures. However, the conchæ are from 10 to 12 mm. in advance of the choanæ and do not configure the outlines of the openings as they do the lateral nasal walls. The dorsal extremities of the nasal conchæ can be inspected through the choanæ, especially the inferior and middle. The definitive choanæ are located farther dorsad than the primitive choanæ which connect the early nasal fossæ with the mouth cavity (see embryology, page 9). The choanæ are bounded cephalically (above) by the alæ of the vomer; laterally by the median plates of the pterygoid processes of the sphenoid; medially by the vomer; and caudally (below) by the horizontal plate of the palate

bone. The muco-periosteum over this osseous framework is continued from the nasal fossæ into the pharynx. The osseous boundaries of the choanæ cause the nasopharyngeal communications to be permanently open and free unless blocked by other structures, *e.g.*, adenoids, etc. The author observed a case of congenital atresia of the choanæ in a term child. Such atresia may be the result of an organization of epithelial plugs which occasionally block the choanæ earlier in fetal life, rarely osseous tissue develops in the organization (Fig. 70).

The vertical diameter of the adult choanæ is always greater than the transverse (coronal); the comparison being shown by the choanal index—$\frac{\text{transverse diameter} \times 100}{\text{vertical diameter}}$. The author found the index for the male to

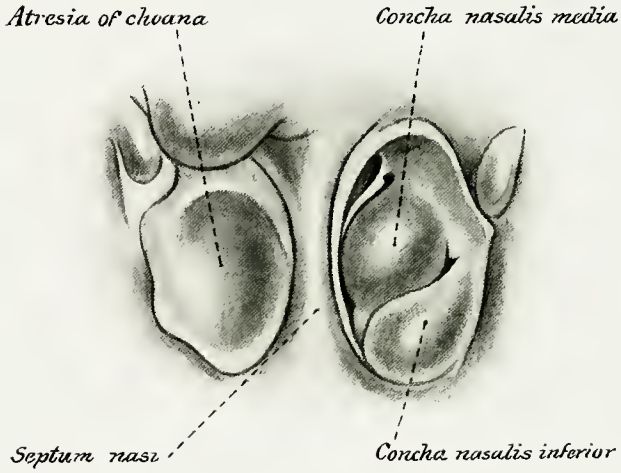

FIG. 70.—Congenital atresia of the right choana in a girl aged 19 years with an accompanying anosmia of the right side. (*After Krieg.*)

be 61 and for the female 64.5. In this he is in close agreement with Escat[1] who gives 60 for the male and 64 for the female. While there may be slight differences in the diameters of the choanæ of the two sides, they are alike in this regard to a remarkable degree. The transverse diameter is greater at the floor (varying from 12 to 17 mm.) and least at the roof (varying from 7 to 10 mm.). The vertical diameter varies from 24 to 33 mm. The vertical diameter is relatively much reduced in the newborn child. There is considerable variation in the inclination of the dorsal free border of the vomer, and as Dwight has shown it is in direct ratio to the degree of prognathism. The gnathic index is the ratio of the line from the basion to the alveolar point to the line from the basion to

[1] Cavité Naso-Pharyngiene, Paris, 1894.

the nasion, *e.g.*, $\frac{\text{basi-alveolar line} \times 100}{\text{basi-nasal line}}$. An index below 98 indicates an orthognathic skull; 98 to 103, a mesognathic skull; and above 103, a prognathic skull.

The Floor of the Nasal Cavity.—The osseous framework of the nasal floor is formed by the palatal processes of the maxillæ and the horizontal processes of the palate bones, Fig. 71. The floor of the nasal cavity serves also as the roof of the mouth. The broad palate is usually less vaulted than the narrow one. The ratio of the breadth to the length is expressed by the palatal index, *e.g.*, $\frac{\text{breadth} \times 100}{\text{length}}$; the breadth being measured through the sockets of the second molar teeth and the length from the alveolar process in the mid-sagittal plane to the posterior nasal spine.

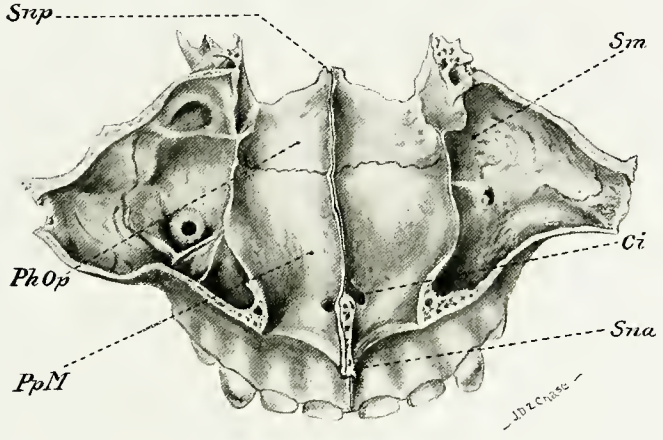

FIG. 71.—A dissection illustrating the floor of the nasal fossæ as related to the maxillary sinuses. *Snp* = spina nasalis posterior; *Sm* = sinus maxillaris; *Ci* = canalis incisivus; *Sna* = spina nasalis anterior; *PpM* = processus palatinus maxillæ; *PhOp* = processus horizontalis ossis palatini.

The generalization often made that narrow palatal arches invariably lead to correspondingly narrow nasal floors is unwarranted. It is in very many instances assuming what is not a cause for narrow nasal floors to be a cause—*non causa pro causa*. The writer[1] first noticed the fallacy of the general inference or premise when studying the relations of the maxillary sinus to the nasal floor (1907–10). Since then many observations have been made to show that the nasal floor and the palatal arch are not necessarily synchronously wide or narrow. Wide palatal arches may be accompanied by relatively narrow nasal floors and narrow arches by wide floors.

[1] J. Parsons Schaeffer: The Sinus Maxillaris and Its Relations in the Embryo, Child, and Adult Man, Amer. Jour. Anat., Vol. 10, 1910.

It is obvious from a study of a sufficiently large series of specimens that the width of the floor of the nasal fossa is more dependent upon the size of the maxillary sinus than upon the degree of arching of the palate, and when one recalls that the right and left maxillary sinuses are often very asymmetrical in size, the difference in width of the floors of the two nasal fossæ is more comprehensible. If the maxillary sinus is small, the nasal fossa near its floor, *e.g.*, the meatus inferior, may bulge laterally over the alveolar process and the related teeth. The reverse may also be true in which the maxillary sinus hollows out beneath the inferior nasal meatus into the palatal process of the maxilla (hard palate, floor of nose) to form the palatal recess of the sinus (Fig. 85). These anatomical variations of the maxillary sinuses obviously must affect the width of the inferior nasal meatus, *e.g.*, the floor of the nasal cavity, regardless of a high or low palatal arch.

The floor of each nasal fossa is essentially horizontal in the sagittal plane, however, a distinct protuberance is present just inside of the limen nasi, over which an instrument must be passed to enter the inferior nasal meatus proper. In the coronal plane the floor of the nasal fossa is concave. Ventrally the floor of the nasal fossa is thick and robust, this gradually diminishing to a very thin plate at the junction with the soft palate.

The Nasopalatine Canals.—Approximately 2 cm. dorsal to the inner margin of the nostril and in juxtaposition to the nasal septum each nasal fossa presents a slight depression in its floor. This depression leads into a small canal lined with mucosa, prolonged from that which lines the inferior nasal meatus. This funnel-shaped tube of mucous membrane, the nasopalatine canal (canalis incisivus, canal of Stenson), courses obliquely caudalward and with its fellow of the opposite fossa converges toward the nasal septum, descends almost vertically and passes through the Y-shaped *incisive foramen* (foramen incisivum, anterior palatine canal) in the hard palate. The right and left nasopalatine canals may join and pass through the stem of the Y incisive foramen as a common channel, however, more commonly each retains its individuality. The canals end on the roof of the mouth at the side of the *palatine papilla* (papilla palatina) or incisive pad (Fig. 196).

The nasopalatine canals are remnants of the wide communication between the nasal and oral cavities found at an early period of fetal life.

Occasionally the nasopalatine canals in adult man lead to a direct communication between the nasal fossæ and the buccal cavity. In the vast majority of instances, however, the lumina of the canals are obliterated and represented by impervious cords of epithelial cells con-

tinuous with the epithelium of the roof of the mouth at one extremity and with the funnel-shaped ciliated epithelial-lined depressions in the floor of the nasal fossæ at the other. Indeed, at times it is difficult to find any remnant of the canals whatsoever. The obliteration of the lumina often begins before birth. In many animals, on the contrary, the nasopalatine canals remain open and persist as such throughout life.

Persistence of the lumina of portions of the nasopalatine canals may be the explanation for "cells" in the maxillæ dorsal to the upper incisor teeth. Indeed, such a "cell" could communicate with either the inferior meatus or the buccal cavity; or in the event that both extremities of the canals became impervious, the central portion (or portions) would be without a drainage channel and could readily become cystic (see sinus maxillaris, page 121).

The Roof of the Nasal Fossa.—The roof of the nasal fossa may be considered as horizontal and wholly formed by the cribriform plate of the ethmoid bone. It may also be considered as a cranially arched structure, with the cribriform plate forming the horizontal middle portion; the body of the sphenoid bone together with the wing of the vomer and the sphenoidal process of the palate bone, the curved dorsal portion; and the frontal and nasal bones, the curved ventral portion. The entire framework is covered by nasal mucous membrane.

Ventrally the roof of the fossa is very narrow, but gradually widens as the choanal aperture is approached. The greatest breadth of the cribriform plate (roof proper) is approximately 5 mm. Ventrally it narrows and allows the lateral ethmoidal masses to come in contact with the perpendicular plate. Cranially the cribriform plate supports the olfactory lobe of the brain and is perforated by foramina for the passage of the olfactory nerves. Ventrally close to the crista galli is a longitudinal fissure (the nasal fissure) for the transmission of the anterior ethmoidal branch of the nasociliary nerve and the anterior ethmoidal vessels.

The Median Wall of the Nasal Fossa, *e.g.*, *The Nasal Septum* (septum nasi).—The partition between the right and left nasal fossæ is formed: (1) by osseous elements, (2) by cartilaginous elements, and (3) by integument (Fig. 74).

The nasal mucous membrane covers all portions of both sides of the septum save the vestibular part which is invested by integument continued through the nares from the surface area. It is smooth and more or less constant in thickness. However, the more extensive glandular and vascular development here and there cause the mucosa to be thrown into relief in the form of small ridge-like elevations and protuberances. A

fairly constant elevation (the tuberculum septi) is found on the septum in juxtaposition to the ventral extremity of the middle nasal concha. Moreover, oblique mucosal ridges or *septal plicæ* (plicæ septi) frequently configure the dorsocaudal portion of the septum. These folds or plicæ, four to six in number, are placed in order from below upward and forward and have as their precursors the mucosal folds which appear early in

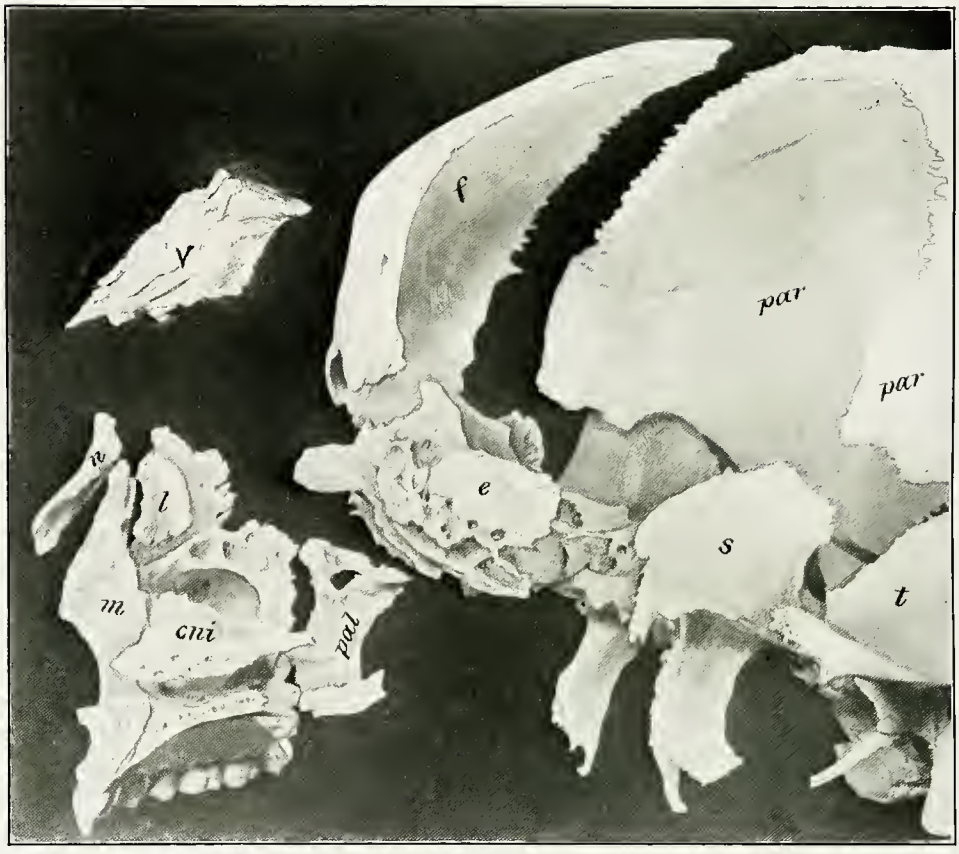

FIG. 72.—Photograph of the separate bones of the nasal fossa, etc.

V = vomer; *f* = frontal; *e* = ethmoid; *s* = sphenoid; *pal* = palate; *Cni* = concha nasalis inferior; *m* = maxilla; *l* = lacrimal; *n* = nasal; *t* = temporal; *par* = parietal.

fetal life (see page 37 and Fig. 41). They usually increase in size up to the eighth month of intrauterine life, then undergo regression and disappear early in infancy. However, occasionally they persist, even hypertrophy into tumor-like obstructing masses in the adult (see page 261 for detailed discussion of the adult nasal mucous membrane).

(A) **The osseous portion of the nasal septum** (septum nasi osseum) is formed by the perpendicular plate of the ethmoid, the vomer, the frontal

(nasal) spine of the frontal, the rostrum of the sphenoid and the crests of the nasal, maxillary and palate bones.

1. The *vomer* is a thin, irregularly quadrilateral bone located in the dorsocaudal portion of the nasal septum. The dorsal border of the bone projects free toward the nasopharynx and separates the choanæ. The inferior border articulates with the nasal crests of the maxillary and palate bones. The superior border, the thickest part of the bone, is divided into two spreading alæ which articulate with the rostrum of the body of the

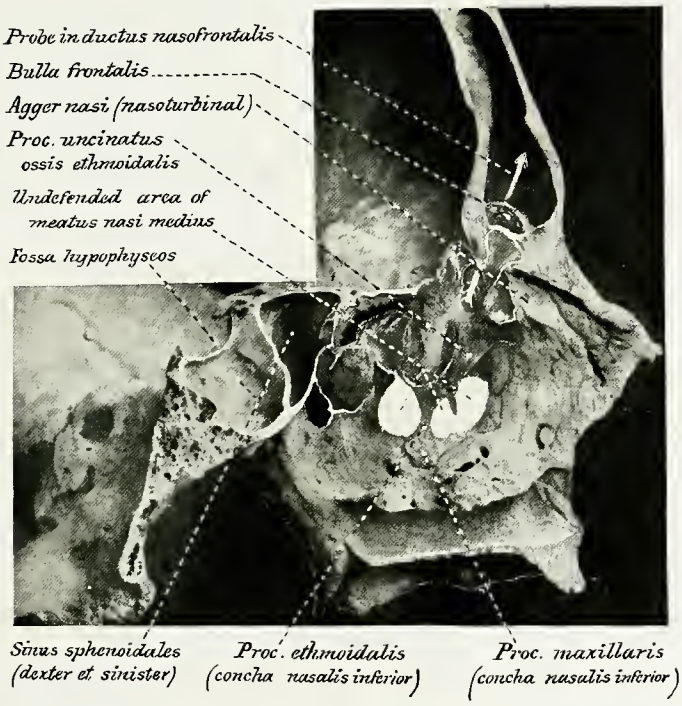

FIG. 73.—The osseous lateral nasal wall with the ethmoidal conchæ or turbinated bones removed. Note the undefended area of the meatus nasi medius and its division into two parts (see text, page 92). Note also the unusual position (frontal plane) of the osseous septum separating the right and left sphenoidal sinuses and the relations of the hypophyseal fossa.

sphenoid bone. Moreover, the edge of each ala meets the vaginal process of the sphenoid and the sphenoidal process of the palate bone. The anterior border is grooved for the reception of the septal cartilage and in the dorsocephalic portion is ankylosed on one or both sides to the perpendicular plate of the ethmoid bone. Occasionally the septal cartilage is prolonged tongue-like between the vomer and the perpendicular plate of the ethmoid in the formation of the sphenoidal process of the septal cartilage (Fig. 74). The ventral extremity of the vomer forms a short

vertical border which abuts the incisive crest of the maxillæ dorsally and is extended variously at its upper end in the groove of the crest. Moreover, the lower end of the ventral extremity at times projects between the incisive canals. Rarely the vomer shares in the formation of the hard palate by extending between the palatine processes of the maxillæ (see development of vomer, page 41).

2. The *mesethmoid* or the perpendicular plate (lamina perpendicularis) of the ethmoid bone represents the ossified upper portion of the primitive cartilaginous nasal capsule. It forms the cephalic third of the septum of the nose, articulating with the frontal (nasal) spine of the frontal

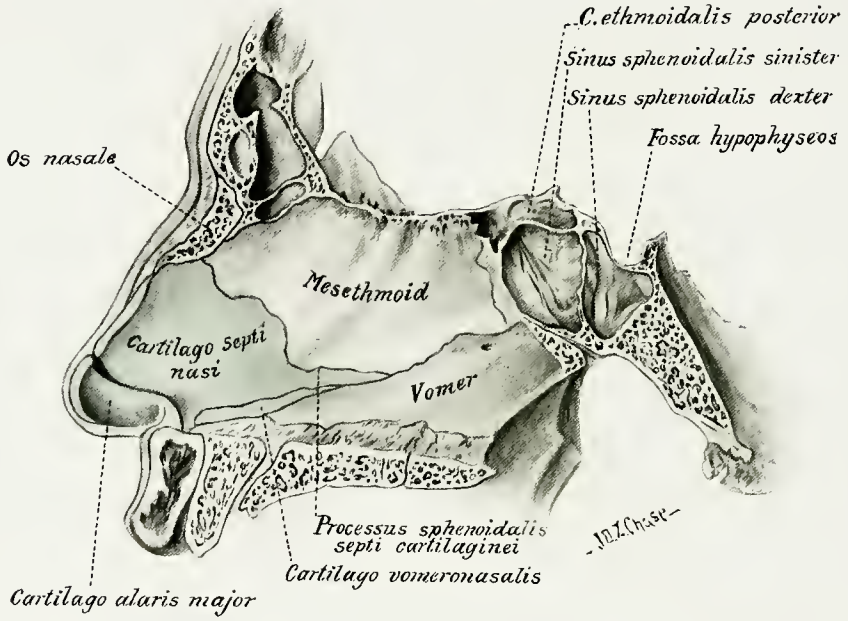

FIG. 74.—A dissection showing the osseous and cartilaginous septum of the nose.

bone and the nasal bones ventrally, with the septal cartilage and the vomer ventrally and caudally (the vomer and mesethmoid may be joined by osseous tissue), and with the crest of the sphenoid dorsally. The cephalic border of the mesethmoid appears in the cranial cavity above the cribriform plate as the crista galli and in doing so divides the roof of the nasal cavity into two halves.

The ventral extension of the mesethmoid varies considerably and in this reciprocates with the related portion of the septal cartilage. Moreover, this accounts for the apparent discrepancies in the literature concerning the osseous extent of the nasal septum. Not infrequently the

mesethmoid extends as far as the caudal or distal border of the nasal bones. Again specimens are encountered in which the mesethmoid is much smaller, terminating ventrally at the level of the frontal (nasal) spine of the frontal bone. All degrees of development between these two extremes are found in a series of specimens. Obviously the septal cartilage is reciprocally large or small in the structural formation of the nasal septum. The variations in the mesethmoid must have a considerable bearing in connection with fractures of the nose and septal deviation.

3. The remaining osseous septal elements—the *frontal* (nasal) *spine* of the frontal, the *rostrum* of the sphenoid and the *crests* of the nasal,

FIG. 75.—The medial or nasal wall of the maxillary sinus exposed from the sinus side. Note the undefended area (4) and that the uncinate process does not articulate with the inferior nasal concha. (Compare with Fig. 73.)

1 = ethmoid; 2 = lacrimal; 3 = uncinate process of ethmoid; 4 = mucous membrane; 5 = palate bone; 6 = inferior concha or turbinate; 7 = maxilla.

maxillary and palate bones—serve as articulating points for the vomer, mesethmoid and septal cartilage and thereby participate in completing the septal margins (Fig. 74).

(B) **The cartilaginous portion of the nasal septum** (septum nasi cartilagineum) is formed by the septal cartilage, the vomeronasal cartilages and the medial crura of the great alar cartilages.

1. *The cartilage of the septum* (cartilago septi nasi) is irregularly quadrilateral in shape and completes the median partition ventrally be-

tween the right and left nasal fossæ. It represents the ventral extremity of the primordial cartilaginous cranium. Its dorsocephalic border is attached to the perpendicular plate of the ethmoid (mesethmoid); its dorsocaudal border to the vomer and maxilla (incisive crest, as far as the anterior nasal spine). Its thick ventrocephalic border is fixed along the internasal suture above and below it becomes confluent with the lateral nasal cartilages, the latter extending wing-like from it. After leaving the position of the lateral cartilages, the ventrocephalic border of the septal cartilage extends between the greater alar cartilages to within a half inch of the tip of the nose, the medial crura of the great alar cartilages intervening between the septal cartilage and the nasal tip. The rotundity of the tip of the nose is due to the rounded confluence of the medial and lateral crura of the greater alar cartilages.

Dorsally the septal cartilage extends variously between the vomer and the perpendicular lamina of the ethmoid (mesethmoid), thus forming the so-called *sphenoidal process of the septal cartilage* (processus sphenoidalis septi cartilaginei). Indeed, the latter may be sufficiently elongated to reach the sphenoid bone—especially in children—and very frequently is the seat of a crista or ridge-like horizontal projection into one or the other nasal fossa, causing septal asymmetry (Fig. 74).

2. *The vomeronasal cartilages* (cartilagines vomeronasales) are two narrow longitudinal strips, 7 to 15 mm. in length, which lie along the ventral portion of the caudal border of the septal cartilage. In this position the vomeronasal cartilages are attached to the vomer dorsally and to the maxilla and the septal cartilages ventrally. The vomeronasal cartilages are not always differentiated from the septal cartilage and appear as lateral processes from its caudal border (Fig. 74). In man these cartilages reach their maximum development in the embryo. They are, however, always most conspicuous in animals in which the vomeronasal organ is well developed, forming a protecting and supporting framework for the organ. It is doubtful in man whether the diminutive vomeronasal cartilages have anything in common with the rudimentary vomeronasal organ, since the latter is always located in the septal tissue cephalic to the position of the vomeronasal cartilages (Fig. 189). Strictly speaking, therefore, one should not say that the latter cartilages are supporting structures for the vomeronasal organ (organ of Jacobson) in homo.

3. *The greater alar cartilage* or cartilage of the aperture (cartilaginea alaris major) is discussed with the cartilages of the external nose to which the reader is referred (Figs. 68 and 69).

(C) **The membranous portion of the nasal septum** (septum nasi

membranaceum) is formed by the medial crura of the great alar cartilages and by integument and subcutaneous tela, the septal cartilage stopping short of it. Owing to the absence of the latter the membranous septum is much more flexible and is often referred to as the *septum mobile nasi* (see greater alar cartilage, page 68, Fig. 68).

Asymmetry of the Nasal Septum.—During fetal life and in infancy and in early childhood, the nasal septum is usually symmetrical and in the mid-sagittal plane throughout. However, the author has seen asymmetrical nasal septa in individuals of the early childhood period and several markedly deviated septa in fetuses. Notwithstanding these exceptions, asymmetries of the nasal septum usually appear after the childhood period, the majority of adults presenting asymmetries varying from slight irregularities to deviations which completely occlude one or the other nasal fossa. Indeed, deflection of the human nasal septum is so common that one almost thinks of it as normal anatomy in spite of the fact that the results of the asymmetry are often so direful that surgical intervention is necessary. One must, however, bear in mind that a goodly number of adults have essentially symmetrical septa and not be misled by the extravagant statements occasionally made that straight septa are *extremely* unusual.

No accurate anatomical classification of septal asymmetries can be made owing to the divers types that may be assumed. The asymmetry may involve all the constituents of the septum or be limited to the septal cartilage or the osseous parts, respectively. Strangely, the dorsal or free border of the nasal septum is nearly always in the mid-sagittal plane so that the choanal apertures are regularly of equal size. In a general way, one may say that septal asymmetry is due to septal deflection as a whole or to one of its major constituents, or to spurs, ridges, etc. Not infrequently the latter in some form accompany septal deflection. Often spurs and ridges are referred to as septal deflections as well.

Very common seats of deflection occur along the articulation between the vomer and the septal cartilage, and the articulation between the mesethmoid and the vomer. The latter articulation is particularly vulnerable when the sphenoidal process of the septal cartilage is interposed for a goodly distance (Fig. 74). At these articulations angular deflections toward one or both sides take place and in addition may give rise to ridge-like folds and crests or to more localized spurs. It must be remembered, however, that the septum may be essentially straight, yet a marked ridge or spur on one or the other side produce an asymmetry. Not infrequently one or the other of the septal elements is, in a sense,

dislocated. A very characteristic crest (crista lateralis) frequently develops along the sphenoidal process of the septal cartilage, and this not necessarily accompanying septal deviation in the strict sense. Corresponding to the variable degree of development of the sphenoidal process of the septal cartilage the lateral crista extends variously along the lateral aspect of the nasal septum, at times as far as the body of the sphenoid bone. At times the entire nasal septum forms a general convexity or bulging into one nasal fossa with a reciprocal concavity and enlargement of the other fossa. Again, the septum may deviate in a double or S-shaped manner, thereby encroaching simultaneously upon both nasal fossæ.

No hypothesis yet formulated seems to adequately explain the occurrence of non-traumatic asymmetry and deflection of the nasal septum in all cases. Many etiologic theories have been advanced and are extant in the literature. The same cause cannot be equally operative in all cases. It is frequently stated that non-traumatic septal deformity is largely a product of ultra-civilization and that it is unknown among animals and savages and rare in all semi-civilized races. The studies of Zuckerkandl seem to confirm this. Moreover, the author recently observed in a mixed series of skulls that the greatest percentage of septal deviation was found in the skulls of Europeans, which is in accord with Zuckerkandl's tables.

Apropos of the latter it may be of interest to mention that the skull in man, as in all mammals, consists of two parts—the facial part, carrying the teeth and developed according to their size, and the brain capsule, which develops in accord with the size of the brain. The larger the brain, the smaller the face and the less does the face project in front of the skull; and, on the contrary, a small brain means a larger face and a greater facial projection in front of the skull. The degree of facial projection from the axis of the skull is spoken of as the facial angle, which is, to a certain degree, an index of brain development. The facial angle is smallest in the ultra-civilized races of man, considerably larger in the lower races, and larger still in the anthropoids. This means that the degree of flexion (angle of flexion) of the cranial axis (basion to nasion line) is greatest in the highly civilized races and lessens as one passes from the lower races to the anthropoids. Moreover, the nasal septum is seemingly encroached upon more and more by the forward cranial extension incident to brain growth as one passes from the anthropoids to the ultra-civilized races of man. The problem, of course, is whether or not there is a balanced adjustment of all parts of the cranium and face in this evolution. If there is, the gradual alteration of the facial angle cannot be a factor in septal asymmetry.

On the other hand, if all parts do not develop in accord with the changes incident to the lessening of the facial angle, one readily sees that the "fixed" position of the nasal septum might be encroached upon and the septum correspondingly deformed.

In studying the nasal septum one is impressed with its anatomical situation. Located as it is between the unyielding frontal and ethmoid bones above and the sphenoid bone behind and the hard palate below, the septum is essentially fixed in position. Any increase in its cephalocaudal (vertical) diameter must necessarily lead to a buckling of the septum as a whole or to a deviation of one of its component elements. It is not clear what would cause the septum to outgrow the region set for it. Possibly a remote and slight trauma may have altered the balanced nutrition and in consequence cause one or more of the septal elements to outgrow its region. The vomer especially seems to be at fault owing to increased development in the vertical plane. Ossification along the line of union between the mesethmoid and the vomer is often excessive and doubtless is an important factor in the deviation of the septum in its ventral two-thirds. Should the cranial and facial bones grow at the expense of the nasal septum the reverse condition would prevail, namely—a deviated septum owing to encroachment upon its area.

Not infrequently one finds enlarged nasal conchæ and enlargement of the entire ethmoidal labyrinth as the obvious causes of septal deviation (Fig. 161).

Great importance is given by Trendelenburg and Freeman to a persistent high or Gothic arch of the hard palate as a causative factor of a deflected nasal septum. This condition would seemingly lead to encroachment upon the vomer and the mesethmoid and cause them to buckle. However, when one finds markedly deviated septa in extremely flat palatal arches he questions the Gothic arch as a factor.

Jarvis and others strongly support the theory of heredity; while Talbot believes that deflected septa are "stigmata of degeneracy" in all cases where traumatism is not a factor. Incoördination or unbalanced development in the growth of the skeleton of the nose and face doubtless account for many deflected septa. Presumably this is the thought Dr. Talbot wishes to convey.

Traumatism, often remote and trivial, is according to many investigators the most frequent cause of septal asymmetry (Bosworth). The author was impressed recently in an examination of a large series of skulls of the relative frequency of some evidence of a previous trauma to the bridge of the nose. The architecture of the framework of the nose is

such that trauma inflicted to the nasal bridge readily influences the cartilaginous portion of the nasal septum. Despite the elasticity and pliability of the nose of the child at term trauma inflicted during birth may be the underlying factor in dislocation of the ventral portion of the nasal septum from the depression formed by the crest of the intermaxillary bone. Indeed, Kyle believes "that many cases of the so-called congenital deformity in the bones of the nose are due to the fact that at birth during labor, owing to the position of the head in the birth canal, considerable pressure has been exerted on the soft, almost cartilaginous, bones of the nose. It is well known that much can be done toward the shaping of the nose at this time." Ballenger, while believing that trauma is a factor in a certain number of cases does not believe that it explains a majority or even a large percentage of deflected septa. He feels that Talbot strikes at the "root of the matter."[1] Hurd[2] likewise believes that "deviation of the septum, which is sometimes traumatic, is usually due to unequal development of the bony frame of the face." It would, therefore, appear established that asymmetries in development and trauma, the latter not infrequently unrecognized at the time, are the most frequent and important etiological factors in septal deformity.

Apparently rickets and septal asymmetry co-exist, as do also septal asymmetry, high-arched palate and nasopharyngeal obstruction. The inter-relations of these conditions, however, need further investigation before any conclusions of value can be given.

Perforation of the Nasal Septum.—Congenital perforation of the nasal septum is apparently a rare condition. In a large series of specimens (well over 300) the author found two instances of congenital perforation, both of which occurred in infantile heads.

The vast majority of perforations of the nasal septum are due to disease: syphilis, tuberculosis, acute infectious diseases (diphtheria, scarlet fever, typhoid fever). Ballenger[3] thinks that atrophic or perforating ulcer of the septum is probably the most common type of perforation. It is well known that septal perforation has followed surgical procedures, moreover, that the persistent use of the patient's finger in attempting to remove crusts from the cartilaginous part of the septum has ultimately led to septal perforation.

The Lateral Wall of the Nasal Fossa.—The lateral nasal wall is divided into two unequal portions by the limen nasi—a small ventral and caudal

[1] Ballenger: Diseases of the Nose, Throat and Ear, Philadelphia, 1914.
[2] Binney's Treatise of Regional Surgery.
[3] Loc. cit.

portion corresponding to the lateral wall of the nasal vestibule and a larger dorsal portion representing the lateral wall of the nasal fossa proper. It is the latter, the most complex of the boundaries of the nasal fossa, that concerns us in this connection. The wall is characteristically configured by the projecting and operculating major and minor (accessory) nasal conchæ or turbinates and by the resultant nasal meatuses and secondary furrows. Moreover, the paranasal (accessory) sinuses, developmentally outgrowths of the nasal mucous membrane, by their ostia and nasal expansion, variously mold the lateral wall. Indeed, the ethmoidal cells may so throw the lateral wall into relief at places that the nasal fossa is reduced to a mere potential cleft.

The osseous framework[1] of the lateral wall is formed *ventrally*, from above downward, by the deep surface of the nasal bone and the medial surfaces of the frontal process and body of the maxilla; *centrally*, from above downward, by the medial wall of the ethmoidal labyrinth and its conchal appendages, the lacrimal bone, the inferior nasal concha and the medial surface of the body of the maxilla; *dorsally*, by the medial surface of the perpendicular plate of the palate bone and pharyngealward by the medial surface of the medial lamina of the pterygoid process of the sphenoid bone (Fig. 72).

The oblong labyrinth or lateral mass of the ethmoid bone is suspended from the nasal surface of the lateral portion of the horizontally placed cribriform plate and, in addition to enclosing numerous irregularly shaped spaces (cellulæ ethmoidales), gives rise to scroll-like masses of overhanging turbinated bones (conchæ ethmoidales). Divergent opinions are held regarding the number of such bones that constitute the typical ethmoidal field in post-fetal life. In a study of 264 lateral nasal walls, the writer found 160 with three ethmoidal conchæ, 98 with two, 4 with four, and 2 with one. From this examination it would appear that three ethmoturbinals (conchæ nasales media, superior, et suprema I) should be considered as the typical ethmoidal field rather than two as is usually stated (Fig. 146). However, it would be better to consider both fields (two and three ethmoidal conchæ) as normal anatomic types since they occur so frequently. Departures from these are relatively few and unimportant (see embryology, Chapter I). Moreover, the independent maxilloturbinal, the concha nasalis inferior, projects from the caudal portion of the bony lateral wall and is similarly overhanging in character. The nasoturbinal (agger nasi) is extremely rudimentary in man and courses parallel to the dorsum of the nose.

[1] Osteological details of individual bones are omitted.

The several nasal conchæ together with the floor of the nasal fossa form ventrodorsally-directed *oblong fossæ*—the meatus nasi inferior, media, superior, et suprema I. The conchæ are always located cephalic to the corresponding meatuses which with the contained structures they partially operculate. Lateralward from the nasal septum and medialward from the projecting and overhanging nasal conchæ remains a cleft-shaped space which extends from the nasal floor to the nasal roof—the *common nasal meatus* (meatus nasi communis), into which the nasal meatuses proper open. Dorsally the nasal meatuses open into the *nasopharyngeal meatus* (meatus nasopharyngeus) which in turn communicates with the choana (posterior naris) and the nasopharynx.

Immediately beyond the vestibule the bony nasal fossa rapidly expands into the *nasal atrium* (atrium nasi, atrium meatus medii). This expansion is wholly due to a saucer-like depression in the lateral nasal wall in advance of the entrance into the middle nasal meatus. Ventrally and cephalically the nasal atrium is limited by the agger nasi, a rudimentary nasoturbinal which in many mammals, *e.g.*, the sheep, dog, pig, etc., attains a very large size. Ventral to the agger nasi and limited by the ental surface of the dorsum of the nose and extending from the nasal aperture to the roof of the nose is a cleft-like passage—the *nasal carina* of Meckel (carina nasi Meckelii), the *olfactory sulcus* (sulcus olfactorius).

Over the entire irregular osseous skeleton of the lateral nasal wall is stretched the nasal mucous membrane; moreover, is continued through the various ostia into the paranasal sinuses and becomes continuous with the mucosa of the nasolacrimal duct. In addition to covering the osseous framework, the mucous membrane bridges over dehiscences in the lateral bony wall of the middle meatus and the median wall of the maxillary sinus (see mucous membrane, page 261, and base or median wall of maxillary sinus, page 111).

The inferior nasal concha (concha nasalis inferior, maxilloturbinal) is an independent, slender, scroll-like lamina of bone developed by ossification in the infolded caudal border of the lateral plate of the cartilaginous nasal capsule. It articulates by its attached border with the turbinate crest (crista conchalis) of the maxilla, then ascends sharply, forms the lacrimal process (processus lacrimalis) which completes the osseous nasolacrimal canal and articulates with the lacrimal bone. Farther dorsad the attached border is folded caudalward in the maxillary process (processus maxillaris) which aids in closing the bony hiatus of the maxillary sinus, and by its convex imbricated border overlaps the margin of the maxillary hiatus and articulates with the palate bone dorsally. A variable

projection (the processus ethmoidalis) extends from the dorsosuperior portion of the attached border of the inferior concha to articulate with the uncinate process of the ethmoid across the maxillary hiatus and with the conchal crista (crista conchalis) of the palate bone behind. The thickened caudal or free border is laterally curled upon itself and at times contains one or more incisuræ, giving rise to bi- or tri-lobed forms of the inferior nasal concha. The lateral surface is concave, the medial convex. The longitudinal ridge on the medial surface may represent (in a rudimentary form) the upper curled plate seen in the gibbon. The elongated dorsal extremity of the inferior concha is sharp and pointed, the mucosa giving it a blunt and rounded appearance in the recent and living state. The ventral extremity is flat, broad and edged and with the overlying mucosa merges gently with the lateral wall. The concha is covered by a thick mucous membrane which contains in its tela submucosa numerous venous plexuses which assume the character and rôle of an erectile tissue—*plexus cavernosi concharum* (Fig. 183). The mucosa-covered lamella of bone extends from a field some distance behind the limen nasi to a point from 10 to 12 mm. in advance of the choana, and in its course overhangs the inferior nasal meatus and the contained ostium of the nasolacrimal duct. In the recent state the attached border of the inferior concha is distinctly arched in the ventrodorsal plane.

The inferior nasal meatus (meatus nasi inferior) is of considerable size, being limited by the arched attached border of the inferior nasal concha cephalically, by the nasal floor caudally, and by the nasal septum and the lateral nasal wall medially and laterally, respectively. It measures from 4.5 to 5.8 cm. in length, beginning variously from 2.5 to 3.7 cm. dorsal to the tip of the nose. As mentioned previously in connection with the floor of the nose, the inferior nasal meatus is narrow at its ventral extremity, however rapidly expanding in width and height and again gradually narrowing as the choanal extremity is reached.

The ostium of the nasolacrimal duct (ostium nasolacrimale) is variously located on the ventral portion of the lateral wall of the inferior nasal meatus. Its position varies from 15 to 20 mm. dorsal to the limen nasi and from 30 to 40 mm. dorsal to the naris (anterior naris). Moreover, its location in the cephalocaudal plane varies likewise. It is frequently found in the extreme cephalic portion (apex of dome) of the inferior meatus immediately caudal to the attachment of the inferior nasal concha to the lateral nasal wall. Again, the lacrimal ostium may be 10 mm. caudal to the above point. Between these two extremes ostia are found at various levels. The ostium nasolacrimale is usually a single opening, however,

duplication and triplication occur (see embryology, pages 50 and 51, and Fig. 177).

The unqualified statement found in many text-books that the ductus nasolacrimalis at the point of communication with the inferior nasal meatus is provided with a mucous-membrane valve (plica lacrimalis or the so-called valve of Hasner) is at variance in very many instances with the real anatomic condition. A study of the ostium nasolacrimale in a large series of cadavers demonstrated to the author that there is no *unvarying typical form*, rather several *normal anatomic types*. The ostium may pass through the nasal mucosa obliquely, be slit-like and indefinite, and essentially a potential cleft guarded by a mucosal flap. Again the ostium may pass through the nasal mucosa directly and be surrounded by osseous walls, thus causing it to stand permanently open as a wide mouth, immediately caudal to the junction-point of the attached border of the inferior concha and the lateral nasal wall. Ostia in the latter position are never guarded by valves or mucosal flaps and are easily located and probed. Another common type of ostium is one in which, extending from the aperture proper, is a fairly deep, gutter-like groove. The latter may become shallower and shallower as the floor of the nose is approached, or become deeper, ultimately ending as a blind pouch. Nipple-like mucosal projections on the lateral wall of the inferior meatus, surmounted by the ostium nasolacrimale, are likewise encountered. Minor departures from these types are common, but unimportant (see Fig. 177 for types).

The middle nasal concha (concha nasalis media) is relatively large. Hanging valve-like over the middle nasal meatus it hides or operculates a number of minor or secondary conchæ and furrows and a variable number of anterior ethmoidal cells. The skeleton of the middle concha is not an independent osseous element, but an appendage of the lateral ethmoidal mass. Over it is stretched a thick mucous membrane rich in venous networks that assume the character of an erectile tissue similar to that of the inferior concha. The heavy mucosa gives the middle concha a robust appearance (Fig. 159).

The free border of the middle concha in the recent state is from 40 to 50 mm. long. It usually presents a marked genu, giving rise to a short ventral vertical limb and a longer dorsal horizontal limb. Occasionally little, if any, angulation occurs. Not infrequently the middle concha undergoes enlargement at the genu in the formation of a distinct lobule. Moreover, a secondary nodule often develops on the free surface of the lobule. Both the lobule and nodule are better developed relatively in the fetus and newborn than in the adult (see page 25 and Figs. 19 and

30). It seems established that the lobule and secondary nodule of the human ethmoidal conchæ (particularly well developed in the middle) are the homologues of the sharp ventral projection of the ethmoturbinals of mammals. Occasionally the lobule of the middle concha assumes large dimensions and mechanically obstructs the middle meatus at this point. Indeed, the mass may crowd the nasal septum toward the opposite side. These lobules must not be confused with enlargements due to ethmoidal (conchal) cells (see page 221 and Figs. 159, 160 and 161).

The attached border of the middle concha ascends ventrally on the surface of the lateral ethmoidal mass to near the roof of the nasal fossa and from here it curves caudally and dorsally to terminate below the junction-point of the ventral and caudal surfaces of the body of the sphenoid bone at the posterior nasal sulcus. The ascending limb of the attached border in the recent state is inconstant in its extent owing to the variability in development of the ascending limb of the superior meatus.

The lateral surface of the middle concha is not infrequently distinctly concave in frontal section owing to a lateral and cephalic curling of its free border. Indeed, the curling may be so marked that a *pseudo paranasal sinus* is formed with a slit-like aperture on the lateral surface of the concha. Such sinus-like inclusions must not be confused with true paranasal sinuses often found in the middle concha (see page 226).

The medial surface of the middle concha frequently presents *secondary furrows*, best marked in the newborn child. Single and deeply cut furrows partially divide the middle concha into superior and inferior portions, the former often erroneously considered the superior nasal concha (see page 26). Occasionally the superior surface of the middle concha near the attached border gives rise to a ridge-like elevation (crista suprema, Killian) which passively deepens the inferior recess of the superior nasal meatus (see page 35 and Fig. 34).

The middle nasal meatus (meatus nasi medius) is the most important and complex of the nasal meatuses, and is developmentally and topographically divided into *ascending* and *descending rami*. The latter is spacious and arched, conforming to the contour of the middle and inferior nasal conchæ; the former much less roomy and in a sense a mere extension toward the frontal region of the descending ramus or middle meatus proper. Moreover, the middle meatus is largely overhung, and its contained structures—the minor or accessory nasal conchæ and meatuses and portions of the ethmoidal cells, together with the ostia of

the latter and those of the frontal and maxillary sinuses—are hidden from view by the valve-like operculating character of the middle nasal concha. Indeed, it is necessary to entirely ablate the middle concha in order to expose the middle nasal meatus for a detailed study (Figs. 153 and 197).

At this juncture it is essential to recall that in the fetus, minor or accessory nasal conchæ or folds with resulting secondary meatuses or furrows are formed on the lateral wall of both the ascending and descending rami of the middle nasal meatus (see page 27). Some of these persist, others lose their identity as such by merging into one, and some disappear altogether (Figs. 25 and 33). In the descending ramus of the middle meatus are developed from the early secondary folds and furrows the definitive *ethmoidal bulla* (bulla ethmoidalis), the *uncinate process* (processus uncinatus), the *suprabullar furrow*, and the *ethmoidal infundibulum* (infundibulum ethmoidale). Occasionally a furrow—a persistent embryonic *bullar furrow*, is formed on the lateral aspect of the ethmoidal bulla. Moreover, the accessory furrows contain ostia of paranasal sinuses. In the ascending ramus (the frontal recess) of the post-pubertal nose are found remnants of fetal frontal or accessory conchæ and furrows in the form of low ridges separating variously anterior ethmoidal cells and the ostia of such cells. Moreover, the frontal sinus bears a varied relation to these regressed folds and furrows.

The lateral wall of the descending ramus of the middle meatus between the caudoventral border of the uncinate process and the inferior concha, between the dorsal extremity of the uncinate process and the perpendicular plate of the palate bone, and between the dorsal extremity of the uncinate process and the ethmoidal bulla may be termed the *undefended C-shaped region* of the lateral nasal wall. Here the mucous membranes of the nasal fossa and the maxillary sinus come into actual contact with each other, there being no intervening osseous skeleton as elsewhere. Moreover, it is in this region that the *accessory ostium of the maxillary sinus* (ostium maxillare accessorium) is variously established (see page 130 and Figs. 75 and 145). Very frequently the C-shaped membranous space is broken into two portions by the articulation of the caudally directed root of the uncinate process with the ethmoidal process of the inferior nasal concha (Fig. 73).

The ethmoidal infundibulum (infundibulum ethmoidale) is the deep crescentic groove or secondary meatus coursing along the lateral wall of the descending ramus of the middle nasal meatus. It is bounded cephalically and laterally by the ethmoidal bulla, certain anterior ethmoidal

cells and the undefended mucous membrane, and caudally and medially by the uncinate process. At its ventral and cephalic extremity the ethmoidal infundibulum usually ends blindly with or without dilatation by forming an anterior ethmoidal cell (Figs. 124 and 125). Moreover, it occasionally terminates in direct continuity with the nasofrontal duct (infundibulum of frontal sinus) or the frontal sinus when the duct is wanting (Fig. 127). The ethmoidal infundibulum either ends blindly dorsocaudally (posteriorly) in a pocket, due to a prominent cephalically arched lamina of the uncinate process, or it ends by gradually becoming shallower and shallower, ultimately losing its identity in the middle nasal meatus—the latter when the upturned lamina of the uncinate process fails to develop sufficiently to form a ledge over which the mucous membrane must course in the formation of a pocket (Figs. 73 and 127).

The ethmoidal infundibulum is in communication with the middle nasal meatus by way of a cleft-like aperture—the *semilunar hiatus* (hiatus semilunaris), located between the free border of the uncinate process and the ethmoidal bulla. The semilunar hiatus is from 15 to 20 mm. long and varies considerably in width, owing largely to the variability in size of the ethmoidal bulla. Indeed, the bulla may be of such size as to come in contact with the free border of the uncinate process, in which case the semilunar hiatus is merely a potential cleft (Fig. 161). The semilunar hiatus extends to the frontal recess and there establishes various relationships with anterior ethmoidal cells and the nasal part of the frontal sinus (see page 160).

The ethmoidal infundibulum is wider near its floor than it is at its semilunar hiatus. Moreover, it gradually becomes wider as its dorssl extremity is neared. The depth, *e.g.*, the distance from the free border of the uncinate process to the floor, varies from 1 to 12 mm.,with an approximate average of 5 mm. Near its dorsal extremity and either in its lateral wall near the floor or in its floor, the ethmoidal infundibulum contains the ostium of the maxillary sinus (ostium maxillare, page 127). At this point the infundibulum is usually at its maximum width. Moreover, the ostia of certain anterior ethmoidal cells (infundibular cells) are variously located in the ventral half of the ethmoidal infundibulum (Figs. 159 and 197).

The uncinate process (processus uncinatus) is a long, thin accessory concha which projects from the ventral portion of the lateral ethmoidal mass or labyrinth under cover of the lacrimal bone. It courses or curves dorsalward, caudalward, and lateralward under cover of the middle

nasal concha in the lateral wall of the middle meatus, and in the articulated skull lies across the hiatus of the maxillary sinus, forming part of the medial or nasal wall of that cavity. The uncinate process at its dorsal and free extremity usually terminates by forming two roots: One, fairly constant, is made up of one or more irregular, caudally-directed projections for articulation with the ethmoidal process of the inferior nasal concha; the other, less constant, curves cephalically behind the dorsal extremity of the ethmoidal infundibulum and when prominent causes the latter in the recent state to terminate in a deep pocket just dorsal to the ostium of the maxillary sinus. This pocket is significant since it is so located that it will direct any fluid coming to the dorsal extremity of the infundibulum ethmoidale through the ostium maxillare into the sinus maxillaris. The uncinate process with its covering of thin mucous membrane forms the caudomedial boundary of the ethmoidal infundibulum and by its free edge the caudal boundary of the semilunar hiatus. It varies in breadth in the recent state from 1 to 12 mm., thereby affecting the depth and the efficiency as a carrier of fluid from the frontal region of the ethmoidal infundibulum (Figs. 127 and 197).

The ethmoidal bulla (bulla ethmoidale) is a bleb-like protuberance of bone, extremely variable in size and shape, projecting from the medial surface of the lateral mass of the ethmoid under cover of the middle nasal concha (Fig. 157). It is excavated by a variable number of ethmoidal cells to which it owes its prominence. The bulla is bounded caudally and dorsally by the semilunar hiatus and the ethmoidal infundibulum and cephalically is limited by the suprabullar furrow into which open most of the cells that honeycomb its mass. Occasionally grooving the medial surface of the bulla is a persistent fetal bullar furrow, which at times contains the ostium of an ethmoidal cell (bullar cell). Rarely in the adult a faint infrabullar furrow (a fetal condition) partially separates the ethmoidal bulla from an infundibular fold (page 31). The furrow may contain the ostium of a small ethmoidal cell. The usual condition, however, is a fusion of the superior and inferior fetal bullar folds in the formation of the adult ethmoidal bulla and for the infundibular fold to lose its identity by obliteration of the infrabullar furrow (see embryology, page 30).

As stated elsewhere, the ethmoidal bulla varies considerably in size, at times feebly developed, again assuming relatively large proportions (Fig. 124). The size of the bulla greatly influences the width of the semilunar hiatus. The bulla when large may come into actual contact with the free margin of the uncinate process. Indeed, it may impinge upon the confines of the uncinate process and crowd it away (Fig. 161). When

the bulla is feebly developed the semilunar hiatus is of considerable width and the drainage of the ethmoidal infundibulum enhanced thereby (Fig. 125).

The suprabullar furrow or recess is a variable, secondary channel grooving the lateral wall of the middle nasal meatus superior to the ethmoidal bulla, *e.g.*, between the latter and the attached border of the middle nasal concha. Notwithstanding that it varies in its form, all specimens give some evidence of it. It may course ventrally and cephalically almost to the cribriform plate of the ethmoid. In the majority of cases it is limited, however, ventrally by fusion between the ethmoidal bulla and the attached border of the middle concha. Similar fusion may limit it dorsally. Not infrequently multiple points of fusion break the suprabullar recess into several compartments, each receiving the ostium of an ethmoidal cell located in the bulla or elsewhere (Figs. 40 and 197). Again, the whole recess may deepen and sink into the body of the ethmoidal bulla, thus forming a large single bullar cell, which causes the ethmoidal bulla to be large and to encroach upon neighboring structures. Ethmoidal cells constantly develop from the suprabullar recess and in the adult such cells are, of course, in communication with it. Rarely the frontal sinus seems to have its genesis from this recess.

The frontal recess (ascending ramus of the middle nasal meatus) is a direct extension developmentally of the middle meatus proper and is intimately related to the genetic and adult anatomy of the frontal sinus and certain of the anterior ethmoidal cells. Its detailed adult anatomy is discussed under the nasofrontal connections (page 160) and the ethmoidal cells (page 205).

The superior nasal concha (concha nasalis superior) is a short thin lamina of bone which projects from the lateral ethmoid mass and overhangs the superior nasal meatus and the structures contained therein. However, it is much less operculating in character than the middle nasal concha (Figs. 129 and 146). The superior concha of the adult is usually represented by a horizontal or descending ramus only. Occasionally, however, a vertical or ascending ramus is differentiated as well. The osseous lamella is covered by a thin mucous membrane directly continued from the general nasal lining. The mucosa is thinner and much less erectile in character than that of the middle and inferior conchæ. In the series of 264 lateral nasal walls examined, the superior nasal concha was absent twice.

The superior nasal meatus (meatus nasi medius) is a channel-like depression on the medial surface of the lateral ethmoidal mass immedi-

ately caudal to the attached border of the superior nasal concha and is often referred to as the *ethmoidal fissure* (Figs. 146 and 195). It is, as a rule, not angulated into ascending and descending limbs as is the middle meatus, but forms a fairly straight channel directed caudalward and dorsalward. Moreover, it is approximately half the length of the middle meatus and overhung to a less degree. Occasionally the superior meatus has a prominent ascending limb grooving the lateral ethmoidal mass almost to the cribriform plate (Fig. 29). Not infrequently an *accessory concha* molds the lateral wall of the superior nasal meatus and divides the latter into *superior* and *inferior* recesses. The inferior recess is usually the better developed and often "erodes" into the superior surface of the attached border of the concha media in the formation of a sinus-like depression which lends prominence to the crista suprema of the middle concha. A thin mucous membrane lines the superior meatus and extends into the posterior ethmoidal cells which communicate with the ventral extremity of the superior meatus and with its superior and inferior recesses.

The first supreme nasal concha (concha nasalis suprema I) persists in the adult in approximately 60 per cent. of individuals. It is a very short, thin lamina projecting from the dorsolateral portion of the lateral ethmoidal mass, slightly overhanging the corresponding nasal meatus. A very thin mucosa covers it.

The first supreme nasal meatus (meatus nasi supremus I) is a shallow, short furrow located on the dorsolateral aspect of the medial surface of the lateral ethmoidal mass immediately caudal to its corresponding concha. As the latter, the meatus is present in about 60 per cent. of individuals, and in approximately 75 per cent. of them a posterior ethmoidal cell communicates with it, indicating a genesis of an ethmoidal cell from it in the fetus (see page 23). A thin mucous membrane lines the meatus and the related ethmoidal cell (Figs. 26 and 127).

The sphenoethmoidal recess (recessus sphenoethmoidalis) is a restricted portion of the nasal fossa located cephalic and dorsal to the highest or most cephalic ethmoidal concha that may be present in the particular case (in approximately 40 per cent. of cases the concha superior is the caudal boundary and in 60 per cent., the concha suprema I). The recess is bounded above (cephalically) by the cribriform plate of the ethmoid bone and dorsally by the ventral surface of the body of the sphenoid bone. The recess is lined by a very thin mucous membrane and contains the ostium of communication of the sphenoidal sinus (ostium sphenoidale) on its dorsal wall. The sphenoethmoidal recess must not be confused

with the superior and the supreme nasal meatuses. Nasal meatuses are always located caudal (inferior) to the corresponding nasal conchæ.

The second and third supreme nasal conchæ (conchæ nasales supremæ II et III) **and the related meatuses** (meatus nasi supremus II et III) are rarely present in the adult human body. Notwithstanding that these structures are at times well differentiated in the fetus (especially the concha suprema II) they usually undergo regression in late fetal and early infantile life and are seldom seen after the second year (Figs. 26 and 28). In the series of 264 adult lateral nasal walls but four specimens were found with four ethmoidal conchæ, *e.g.*, the conchæ nasales media, superior, suprema I, et suprema II. In no instance was a persistent concha suprema III observed.

The agger nasi (nasoturbinal) is a low ridge-like elevation in the macerated skull on the medial surface of the frontal process of the maxilla, coursing caudal- and ventralward from the ventral extremity of the middle nasal concha immediately ventrocephalic to the nasal atrium and extending more or less parallel to the bridge of the nose. In most mammals the nasoturbinal is well developed, while in man it is extremely rudimentary, reaching its maximum development, as a rule, in the late fetus and the infant. In the recent state the nasal mucous membrane gives the agger nasi additional prominence. Not infrequently ethmoidal cells grow out from the ethmoidal infundibulum and from the frontal recess into the agger nasi, forming the so-called agger cells (Figs. 153 and 197).

The nasal atrium (atrium nasi, atrium meatus medii) is a triangular expansion of the nasal fossa beyond the nasal vestibule. The expansion is primarily due to a variable saucer-like depression or lateral arching in the lateral nasal wall in advance of the entrance to the middle nasal meatus. Coursing obliquely caudalward and ventralward the agger nasi delimits the nasal atrium from the deep surface of the dorsum of the nose. In a sense the atrium is the related meatus of the agger nasi (nasoturbinal) and is much more prominent in those forms with a well-developed nasoturbinal. In man it frequently encroaches upon the lumen of the maxillary sinus by causing the nasal or medial wall of the sinus to be convex (Fig. 146).

The olfactory sulcus (sulcus olfactorius, carina nasi) is a channel-like space lying ventral to the agger nasi and limited by the rounded or arched confluence of the medial and lateral nasal walls. It extends from the vestibulum nasi along the ental surface of the dorsum of the nose to the pars olfactoria of the nasal fossa. At the roof of the nose it becomes confluent with the space immediately caudal to the cribriform plate which

in turn becomes the recessus sphenoethmoidalis farther dorsally. The latter contains the ostium sphenoidale on its dorsal wall. It is obvious, therefore, that by following the several segments of this continuous channel along the dorsum and roof of the nose the ostium of the sphenoidal sinus may be located. Moreover, it is believed that odoriferous gaseous substances readily reach the olfactory mucosa through the olfactory sulcus (Fig. 146).

III—THE MAXILLARY SINUS

CHAPTER III

THE MAXILLARY SINUS

The Fetal Stage

The maxillary sinus (sinus maxillaris, antrum of Highmore), primitively a pouching or evagination of the mucous membrane of the floor or lateral wall of the ethmoidal infundibulum (infundibulum ethmoidale), is evident about the seventieth day of fetal life. It is difficult of appreciation in its initial state from an examination of serial sections only, but is well demonstrated by reconstructing at a considerable magnification the ethmoidal infundibulum. The rudiment or anlage of the sinus is usually represented by a single pouch; however, two pouches growing side by side from the ethmoidal infundibulum have been observed by the writer. Again, the pouch may be relatively large at the outset, making it difficult to determine where the ethmoidal infundibulum ends and where the initial rudiment or maxillary sinus begins. In such cases the ethmoidal infundibulum is in a sense a part of the maxillary sinus. One should, however, consider the maxillary sinus as developing from the pre-existing furrow (infundibulum ethmoidale) and not consider the latter a part of the sinus. However, as stated before, it is difficult at times to draw this distinction, especially so when the primitive maxillary sinus is extensive and occupies the greater portion of the infundibulum ethmoidale in its early pouching (Figs. 76–77).

The duplication and extensive pouching of the primitive maxillary sinus, occasionally encountered, is in accord with adult conditions. The adult ostium maxillare varies from a small round or oval aperture to a long slit-like cleft, and is either single or duplicate. The initial doubling of the maxillary sinus doubtless explains some of the duplications of the adult ostium maxillare. It is not unreasonable to believe that in some instances fusion of the double maxillary pouch takes place distally, leaving the points of initial outgrowth as the duplicate ostium. Furthermore, the doubling of the primitive maxillary-sinus pouch may explain some of the *rare* double adult maxillary sinuses, each with an independent ostium in communication with the ethmoidal infundibulum, *i.e.*, each evaginating sac developing independent of its mate.

Instances in which one of two unilateral maxillary sinuses communicated with the superior nasal meatus have been recorded by Zuckerkandl and others. The writer recently made a number of similar observations (Figs. 73 and 101). There is no doubt whatever that the additional maxillary sinus in these cases is truly an ethmoid cell which developed beyond the confines of the ethmoid field into the maxilla. Genetically, such a sinus is ethmoid; topographically, maxillary. Indeed, the maxilla

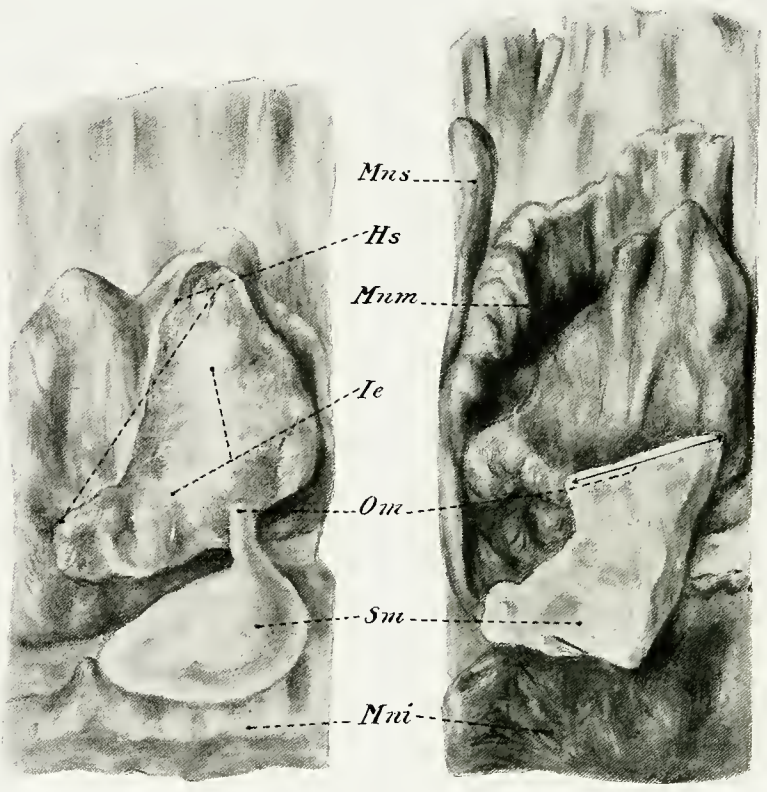

FIG. 76. FIG. 77.

FIGS. 76 and 77.—Drawings of reconstructions of portions of the right nasal fossa including the meatus nasi, infundibulum ethmoidale, hiatus semilunaris and sinus maxillaris. The figure to the reader's left is from a human embryo aged 105 days and that to the right from a human embryo aged 120 days. It must be understood that both models represent cavity and are, therefore, negatives. Particularly note the maxillary sinus at these ages, and the unlike size and shape of the ostium maxillare in the two specimens. × 12.

Mns = meatus nasi superior; *Hs* = hiatus semilunaris; *Mnm* = meatus nasi medius; *Ie* = infundibulum ethmoidale; *Om* = ostium maxillare; *Sm* = sinus maxillaris; *Mni* = meatus nasi inferior.

regularly aids in completing the osseous boundaries of certain ethmoid cells. Brühl's case in which an additional maxillary sinus, that is, a sinus present in duplicate, communicated with the inferior nasal meatus is difficult of genetic interpretation, since ordinarily no paranasal sinus

communicates with this meatus and none develops from it. In all probability the ostium of communication in Brühl's case was secondary and doubtless formed in a manner similar to the very common ostium maxillare accessorium found in the middle nasal meatus in connection with the usual single maxillary sinus (Fig. 108).

The frequent great dimensions of the adult ostium maxillare may be due to a merging of two or more primitive maxillary pouches, or the primitive pouching may have been single, but very extensve, occupying a goodly portion of the floor of the ethmoidal infundibulum.

FIG. 78.

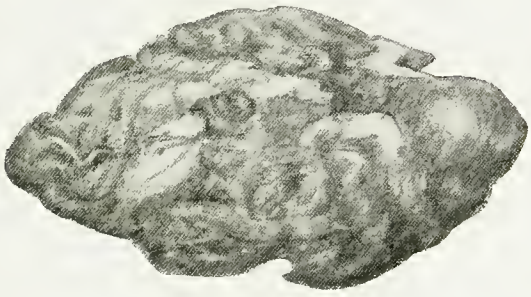

FIG. 80.

FIG. 79.

FIG. 81.

FIGS. 78–81.—The lining mucous membranes of maxillary sinuses removed from formalized cadavers. The illustrations represent the exact shapes of the maxillary sinus as found in these bodies. ×4. (*After J. P. S.*)

Fig. 78, from a fetus aged 4 months; Fig. 79, from a fetus at term; Fig. 80, from a child aged 18 to 20 months; Fig. 81, from a child aged 20 to 23 months.

The early maxillary sinus is for a time a slit-like cavity in the membranous lateral wall of the nose. It extends inferiorly into the recess formed by the union of the lateral cartilaginous plate with that of the inferior nasal concha. By resorption of the cartilaginous nasal capsule intervening between the maxilla and the developing maxillary-sinus sac the latter ultimately comes into actual and direct relationship with the maxilla. By the simultaneous processes of resorption of surrounding bone and the growth of the maxillary pouch, the primitive cavity gains more and more capacity and sinks into the body of the maxilla. It has

its greatest measure in the ventrodorsal direction, while mediolaterally the cavity occupies comparatively little space. In embryos aged from 100 to 105 days the ventrodorsal measurement is about 2 mm. In a 120-day embryo the distance is about 2.5 mm. In a 100-day embryo the most ventral spur of the sinus is about 6.5 mm., and the most dorsal spur 8.5 mm. from the tip of the nose (Figs. 78, 79, 80 and 81).

It will be remembered in the embryo the processus alveolaris of the maxilla is in proximity to the orbit, and when one recalls the fact that the unerupted teeth are contained in this situation, it at once becomes evident that the maxillary sinus must be correspondingly small at this time. Because of these facts the sinus of a 7-month fetus measures only 5 mm. in the ventrodorsal plane and in a fetus at term approximately 7 mm. During the latter months of intrauterine life the sinus gains in the mediolateral plane and at term measures from 3 to 4 mm. The extension of the maxillary sinus into the body of the maxilla takes place *para passu* with the growth of the face (Fig. 84).

The appended table, A, gives the approximate size of the maxillary sinus at various stages of fetal life:

TABLE A

Age	Ventrodorsal (length)	Mediolateral (width)	Cephalocaudal (height)
100 days	2.0 mm.	Potential	0.5 mm.
120 days	2.5 mm.	Potential	0.8 mm.
210 days	5.0 mm.	2.0 mm.	4.0 mm.
Term fetus	7.0 to 8.0 mm.	3.0 to 4.0 mm.	4.0 to 6.0 mm.

THE CHILDHOOD STAGE[1]

The size and shape of the maxillary sinus at birth varies considerably as is evidenced by a study of a large number of still-born babies; indeed, the variation continues into adult life. However, one must not be misled by an apparent variance in size, due to sectioning the sinus in unlike planes—horizontal, coronal and sagittal. Writers often give measurements without stating the plane and this obviously leads to error and an apparent rather than a real discrepancy in results.

The ventrodorsal (length) measurement is always the greatest and up to the end of the third year the cephalocaudal (height) measurement of the sinus is intermediate between the ventrodorsal and mediolateral

[1] The term "childhood" is sometimes restricted to the time between infancy and youth; however, here the term is meant to apply to the period from birth to puberty.

(width). However, during the sixth year the mediolateral measurement gains, but seldom exceeds the cephalocaudal measurement. The cavity is never spherical as is often stated. For some time the maxillary sinus

FIG. 82.—Photograph of a semi-frontal section of a child's face aged from 16 to 18 months. Particularly note the infraorbital canal and nerve and the maxillary sinus. ×0.8
Ninforb = Nervus infraorbitalis; *Smax* = Sinus maxillaris.

is not sufficiently developed in width to reach beneath the orbit. By the end of the first year it has grown sufficiently in this plane to extend beneath the orbit, but not beyond the position of the infraorbital canal.

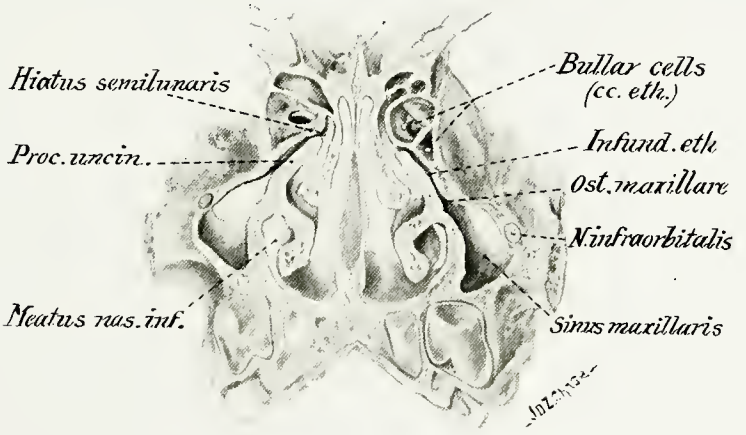

FIG. 83.—A frontal section through the nasal fossæ and the paranasal sinuses at the level of the ostium of the maxillary sinus in a child aged approximately seven years. ×1.

and at the twentieth month it has elongated in the ventrodorsal plane to 20 mm., and has, as a rule, extended above the rudimentary first permanent molar tooth. During the third and fourth years the maxillary

sinus makes a conspicuous growth in the mediolateral plane (width). By the seventh year the sinus measures on the average 27 mm. in the ventrodorsal plane, 17 mm. in the superoinferior plane, and 18 mm. in the mediolateral plane (Fig. 83).

It is generally stated that the deciduous teeth hold the maxillary sinus in check, and that the cavity rapidly assumes larger dimensions as

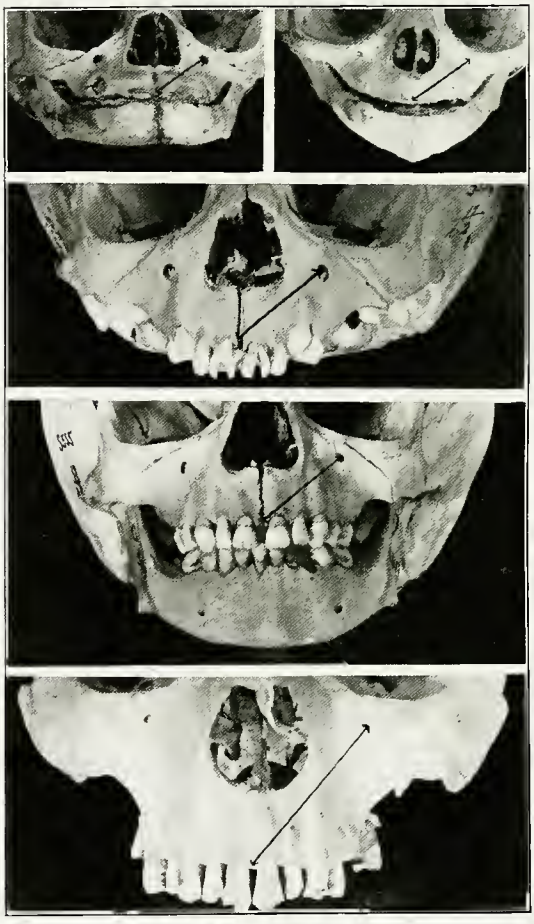

FIG. 84.—Skulls indicating the increase of distance between the infraorbital foramen and the midpoint of the upper jaw from birth to adult age.

the first dentition progresses. The author finds, however, that the growth of the sinus is rather uniform and that the first dentition has little to do with any rapid increase in the size of the cavity. The age of the child, dentition, and the size of the maxillary sinus progress *para passu*. It is, however, obvious that until the teeth erupt and the alveolar process develops there can be little room for the maxillary sinus (Fig. 84).

It is well to remember that in the infant the inferior nasal meatus does not come into the same intimate relationship with the maxillary sinus as in the periods following the eighth to the twelfth years. The relations with the middle nasal meatus are much more intimate and should be borne in mind when the maxillary sinus is to be explored endonasally in the young child. Moreover, the inferior nasal meatus is exceedingly narrow at this time due to the relatively large inferior nasal concha and the heavy mucosa (see page 20). Seemingly, the middle nasal meatus and the general nasal cavity alone serve as respiratory passages at this time. By the eleventh or twelfth year the inferior meatus is enlarged and the maxillary sinus has grown sufficiently toward the alveolar process to be accessible for puncture in the usual adult site, *e.g.*, in the inferior nasal meatus. However, the writer has observed maxillary sinuses in intimate relationship with the inferior nasal meatus at term (Fig. 156).

The operator needs to be cautious in endonasal procedures on the maxillary sinus of the infant from the inferior meatus. The instrument is readily pushed through the soft structures of the cheek and the sinus cavity missed entirely, or both the medial and lateral walls may be penetrated. Again, it would seem wise to use the middle nasal meatus until after the eruption of most of the permanent teeth. The operator must always remember that the rudiments of both the deciduous and permanent teeth are present in the maxilla at the time of birth, there undergoing further development up to the time of dentition. Injury to a "tooth germ" would lead either to death of the part or to the eruption of a deformed tooth ultimately. Surgically, in both the endonasal and the canine fossa approaches of the maxillary sinus in the young child, the narrow mediolateral (transverse) diameter of the maxillary sinus must not be forgotten.

The appended table, B,[1] gives the size of the maxillary sinus in a series of specimens from birth to 15 years of age. Owing to the scarcity of material at the childhood period some observations are limited to few specimens. After the fifteenth year the sinus in a sense passes into the adult stage. It will be noted that after this period the sinus enlarges principally in its vertical diameter (superoinferior) and in its diagonals. The ventrodorsal and mediolateral measurements are nearly the adult average:

[1] See also Warren B. Davis, Nasal Accessory Sinuses, Philadelphia, 1914, for valuable and instructive tables of measurements of the paranasal sinuses of the childhood period.

TABLE B

Age	Ventrodorsal (length)	Cephalocaudal (height)	Mediolateral (width)
Newborn	7.0 to 8.0 mm.	4.0 to 6.0 mm.	3.0 to 4.0 mm.
6 months	10.0 to 10.5 mm.	4.0 to 5.0 mm.	4.0 to 4.5 mm.
9 months	11.0 to 14.0 mm.	5.0 to 5.0 mm.	5.0 to 5.5 mm.
1 year	14.0 to 16.0 mm.	6.0 to 6.5 mm.	5.0 to 6.0 mm.
1.5 years	20.0 to 20.5 mm.	8.0 to 9.0 mm.	6.0 to 6.5 mm.
2 years	21.0 to 22.0 mm.	10.0 to 11.0 mm.	8.0 to 9.0 mm.
3 years	22.0 to 23.0 mm.	11.0 to 12.0 mm.	9.0 to 10.0 mm.
6 years	27.0 to 28.0 mm.	16.0 to 17.0 mm.	16.0 to 17.0 mm.
8 years	28.0 to 29.0 mm.	17.0 to 17.5 mm.	17.0 to 18.0 mm.
10 years	30.0 to 31.0 mm.	17.5 to 18.0 mm.	19.0 to 20.0 mm.
12 years	31.0 to 32.0 mm.	18.0 to 20.0 mm.	19.0 to 20.0 mm.
15 years	31.0 to 32.0 mm.	18.0 to 20.0 mm.	19.0 to 20.0 mm.

It is of interest here to note adult average measurements of the maxillary sinus for comparison: ventrodorsal 34 mm., superoinferior 33 mm., and mediolateral 23 mm.

The skiagram is of great value in early childhood in following the growth of the maxillary sinus and, since considerable variation in the manner of pneumatization of the body of the maxilla is met with, skiagraphy is almost indispensable when operative procedures become necessary.

Even though the maxillary sinus is a cavity of considerable size in the newborn, often measuring 8 by 4 by 6 mm., it is not always demonstrable in skiagrams. This is probably due to the slit-like shape of the sinus and the fact that it hugs the lateral wall of the nasal fossa closely. Even at this early time the sinus is of considerable clinical importance. At the end of the first year the maxillary sinus is still medial to the infraorbital foramen. The skiagram usually delineates it well, since the cancellous maxilla readily allows the rays to pass. Later, say at the end of the second year, the maxillary sinus has pneumatized up to the infaorbital foramen and is more or less triangular in shape and is somewhat obscured in skiagrams by shadows of the petrous portion of the temporal bone and the unerupted permanent teeth (Fig. 92). However, it is clearly indicated along the infraorbital margin. At 5 years of age the maxillary sinus has extended considerably beyond the infraorbital canal. At 9 years it has pneumatized the zygomatic process of the maxilla in the formation of the recessus zygomaticus. The extension into the zygomatic process is as a rule not visible on X-ray plates.

Clinically, it is very important to know the degree of development in a particular case of the recessus alveolaris when the maxillary sinus is operated upon by way of the nasal fossa. While the age of the child is a

valuable guide (see table B, page 108), the skiagram after all must give the surgeon the definite and precise information concerning the pneumatization of the alveolar process in the case before him. In the interpretation of skiagrams one must recall that in ventrodorsal pictures of the maxillary sinus the second and third (sometimes the first also) molar teeth throw a heavy shadow upon the floor of the sinus, which is confusing. Haike has shown that the recessus alveolaris, *e.g.*, the degree of pneumatization of the alveolar process, is best demonstrated in the child by taking a profile view of the face. The profile skiagrams show this recess in children as early as the sixth and seventh year, especially so at the ventral part of the floor of the maxillary sinus. It is well to remember, however, that the alveolar process of the maxilla is not fully pneumatized by the alveolar recess of the maxillary sinus until the time when the permanent teeth have erupted.

The Adult Stage

General Considerations.—The adult maxillary sinus was known to Galenus (130--201), but Dr. Nathaniel Highmore was the first to give any detailed description of it. In his work (1651), "*Corporis Humani Disquisitio Anatomica*," he describes the cavity in the maxilla, to which his attention was drawn by a lady patient, in whom an abscess of this cavity, since frequently referred to as the antrum of Highmore, was drained by the extraction of the left canine tooth. The sinus described by Highmore must have been exceptionally large since the canine tooth does not as a rule come into relationship with the sinus. Some writers even today refer to the canine tooth as the proper drainage site in sinus treatment when the endonasal approach is not utilized. The belief that the canine tooth socket commonly bears an *intimate* relationship to the floor of the maxillary sinus is archaic and must be abandoned.

The adult maxillary sinus, located in the body of the maxilla, is the largest of the paranasal sinuses, save in exceptional cases when it is comparatively small and exceeded in size by the frontal and sphenoidal sinuses. It lies lateral to the cavum nasi and resembles in shape a three-sided pyramid. It follows in the main the shape of the body of the maxilla; and may be described as having a roof, a floor, and three walls. The walls of the sinus vary in thickness, usually from 5 to 8 mm., but may be reduced to a papery delicacy. The writer has, indeed, observed dehiscences in the facial or ventral osseous wall of the sinus. The median wall or base is directed toward the cavum nasi and the apex extends into the median root of the processus zygomaticus of the maxilla, or beyond it into the maxillary border of the zygomatic bone.

The *ventral wall* of the cavity corresponds to the anterior or facial surface of the maxilla, looking ventrolaterally. Part of this wall is at times greatly approximated to the dorsal wall and base of the sinus due to a very prominent canine fossa (fossa canina). Occasionally the whole ventral wall bulges markedly into the cavity of the maxillary sinus.

FIG. 85.—Photograph of a skull with the frontal and maxillary sinuses exposed for study. Particularly note the asymmetry of the frontal sinuses and the bulla-like appearance of the left frontal sinus (see text, page 152). Note also the extreme development of the palatine recess of the maxillary sinus. On both sides the maxillary sinus extends markedly into the palatine process of the maxilla, thereby gaining a conspicuous relationship to the floor of the nasal fossa.

The *dorsal wall* of the sinus corresponds to the infratemporal surface of the maxilla. It is a thin plate of bone, also forming the ventral boundary of the infratemporal and pterygopalatine fossæ. The dorsal is usually

the thickest of the sinus walls. It is, however, occasionally extremely thin (the processus alveolaris being recognized as the floor of the cavity and not as a wall).

The *median wall* or base is directed toward the cavum nasi. It normally presents a very irregular orifice (*hiatus maxillaris*) in the disarticulated bone. In the articulated skull the hiatus is partly filled in by the pars perpendicularis of the palate bone, the processus uncinatus of the ethmoid bone, the processus maxillaris of the inferior nasal concha and a portion of the lacrimal bone. In the recent and living state the nasal mucous membrane bridges over the dehiscences or defects in the osseous median wall, covers the bones and is continued into the maxillary sinus in the formation of a rounded opening (the *ostium maxillare*). The latter may be duplicated, but such duplication must not be confused with the *ostium maxillare accessorium*, which is a direct passageway between the sinus and the nasal fossa. The ostium maxillare (or ostia maxillaria) establishes communication between the sinus and the infundibulum ethmoidale. The medial wall immediately inferior to the attachment of the inferior nasal concha is thin and easily punctured. This wall also forms the lateral boundary of the nasal fossa which often encroaches upon and reduces the size of the cavity of the maxillary sinus. The nasal fossa is, of course, correspondingly increased in size (Fig. 85).

The *roof* of the maxillary sinus is a very thin plate of bone, at times of a papery delicacy, forming the floor of the orbit and the orbital surface of the maxilla. Not infrequently it is modeled by a ridge thrown into relief by the infraorbital canal. In some instances, the ridge is replaced by a groove which is covered over by the mucous membrane of the maxillary sinus. At times the roof of the sinus is partially divided into two plates, separated by ethmoidal air cells (Fig. 102). Occasionally the palate bone aids in forming the roof of the maxillary sinus.

The *floor* of the maxillary sinus is formed by the processus alveolaris of the maxilla. It is by far the thickest of the osseous boundaries of the cavity—the thickness of the floor depending upon the degree of pneumatization of the process. In cases where the pneumatizing process has been carried far, the floor of the sinus bears an important relation to some of the teeth and their sockets. The floor may be thrown into irregular elevations by the fangs of the teeth, depending upon the thickness of the layer of spongy bone. The latter varies in thickness in different skulls. Moreover, there is considerable asymmetry on the two sides of the same skull.

The Relation of the Sinus Floor to the Nasal Floor.—The relation of the floor of the maxillary sinus to the floor of the nasal fossa depends

largely upon the degree of hollowing out of the processus alveolaris of the maxilla. The degree of arching of the hard palate, thereby affecting the floor of the nose, also has some bearing on this relation. When the layer of spongy bone is thin, *e.g.*, the processus alveolaris markedly pneumatized by the maxillary sinus, the floor of the nasal fossa is caudal to the floor of the sinus. On the other hand, when the processus alveolaris is relatively thick the floor of the nasal fossa is caudal to that of the sinus. Occasionally both floors are in the same plane. When the ventral (facial) surface of the maxilla and the lateral wall of the nasal fossa are simultaneously bulging toward the maxillary sinus and at the expense of its lumen, the floor of the nasal fossa is, as a rule, caudal to the floor of the sinus. Notwithstanding these departures, the majority of maxillary sinuses have their floors at varying distances caudal (below) the level of the floor of the nasal fossa. In an examination of 120 adult specimens 78 were found in which the sinus floor was the more dependent, 24 in which the fossa floor was the more dependent, and 18 in which the sinus and fossa floors were in the same plane.

The difference in levels of the floors of the maxillary sinus and the nasal fossa varies from $\frac{1}{2}$ to 10 mm. C. Reschreiter[1] claims that it is a male characteristic to find the sinus floor at a level caudal to that of the nasal fossa. The writer's observations do not confirm this. In an examination of 30 specimens taken from female cadavers, 20 showed the sinus floor to be the more caudal, 6 the nose floor, and in 4 instances the floors to be on the same level. Moreover, the differences in level between the two floors varied in accord with that given above for the male.

Relations of the Maxillary Sinus to the Teeth.—Since the maxillary sinus varies greatly in size in different skulls and on the two sides of the same skull, it is obvious that the relations of the teeth to the sinus cannot be constant. As stated before, the layer of spongy bone between the roots of the teeth and the floor of the maxillary sinus varies in thickness in different skulls and the asymmetry on the two sides of the same skull is at times marked. When the layer of spongy bone is relatively thin the projecting tooth fangs form elevations, of a greater or less degree, on the floor of the sinus. These elevations at times aid in recess formation (Figs. 86 and 87). Direct communication between the fangs of the teeth and the mucous membrane of the sinus, due to extreme hollowing out of the processus alveolaris of the maxilla, occurs most frequently in the aged; however, it does occur in the young adult. That very intimate relations frequently exist between the teeth and the maxillary sinus is a fact that one

[1] Zue Morphologie des Sinus Maxillaris, Stuttgart, 1878.

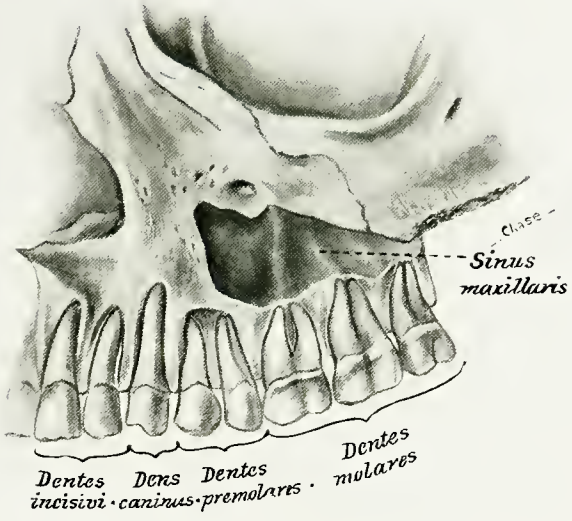

FIG. 86.—A dissection showing the relations of the permanent teeth to the sinus maxillaris. (Compare with Fig. 87.)

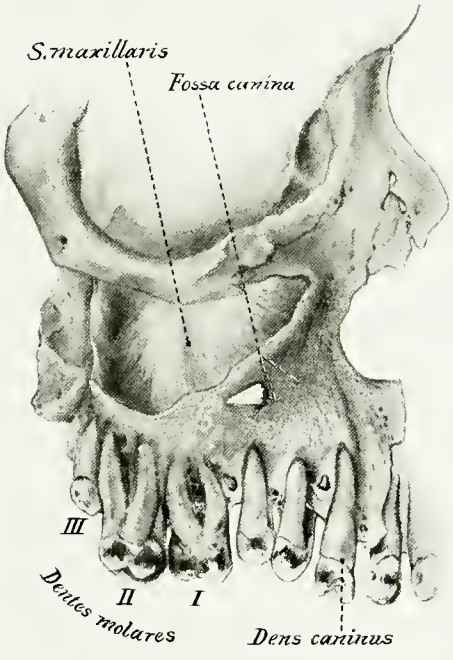

FIG. 87.—A dissection showing the relations of the permanent teeth to the sinus maxillaris. Note that the first molar and the two premolars are not in intimate relationship to the floor of the maxillary sinus. Note the deep canine fossa and the emergence of a perforator pushed from the inferior meatus, escaping the maxillary sinus altogether (see page 114).

should be cognizant of. However, the writer believes that these intimate relations have been exaggerated by some authors. Some clinicians hold to the belief that more cases of dental trouble are due to maxillary sinus disease than the reverse.

The number of teeth that bear a direct relation to the sinus is necessarily inconstant. In exceptional cases when the cavity of the maxillary sinus is very large—especially in the line of the ventrosuperior diagonal—all of the teeth of the *true* maxilla may be in relation to the floor of the sinus. It is, however, only an occasional occurrence to have the canine tooth in direct relation to the sinus. In a certain number of cases the first premolar tooth bears a direct relation to the cavity and in a slightly

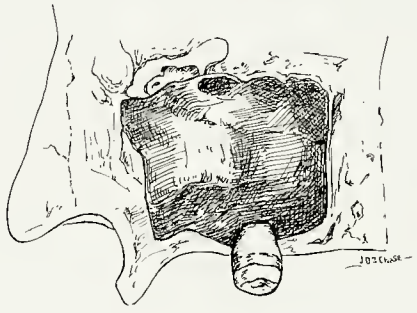

Fig. 88.

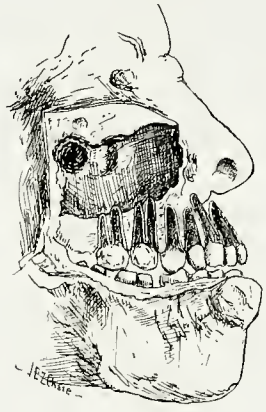

Fig. 88A.

Fig. 88.—From an old person. Note the atrophy of the alveolar process and the projection of the remaining tooth into the lumen of the maxillary sinus.

Fig. 88A.—From a young adult. Note that despite a thick alveolar process the roots of the molar teeth project into the maxillary sinus.

larger percentage the second premolar bears a similar relationship. The three most constant teeth, however, in intimate and vital relationship with the floor of the maxillary sinus are the molars, and when the sinus is small the first molar must be omitted in this relationship.

It is a fairly safe rule to follow when the canine fossa (fossa canina) and the lateral nasal wall are simultaneously approximated at the expense of the lumen of the maxillary sinus, that the canine and premolar teeth do not bear a direct relation to the maxillary sinus. In such cases a perforator pushed through a premolar-tooth socket might readily enter the lateral nasal wall—even pass through it, passing entirely free of the sinus cavity. Again, if the perforator were pushed through the lateral nasal wall, caudal to the inferior nasal concha, the instrument could readily be

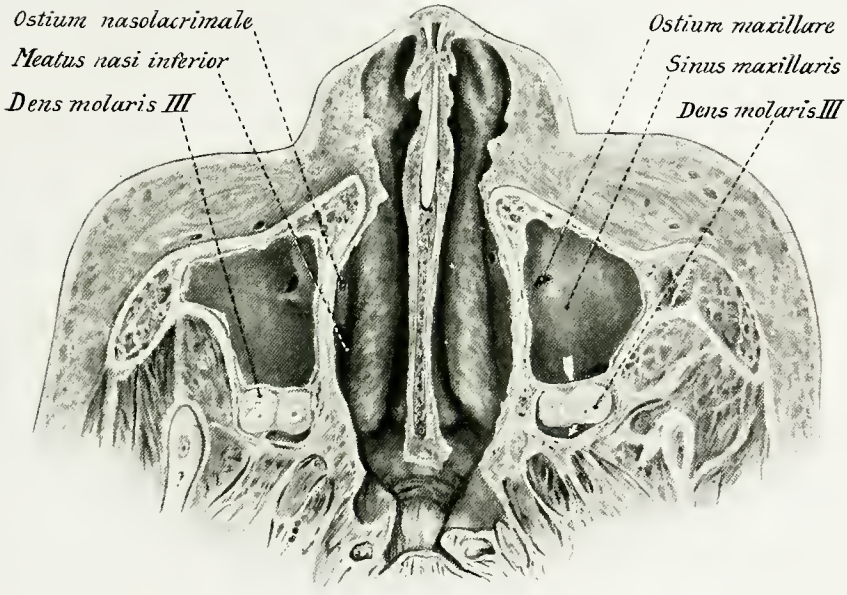

FIG. 89.—A dissection looking into the roof of the inferior nasal meatus and into the roof of the maxillary sinus. The ostia of the nasolacrimal ducts and of the maxillary sinuses are, therefore, displayed. Particularly note the impacted third molar teeth about to erupt into the maxillary sinuses.

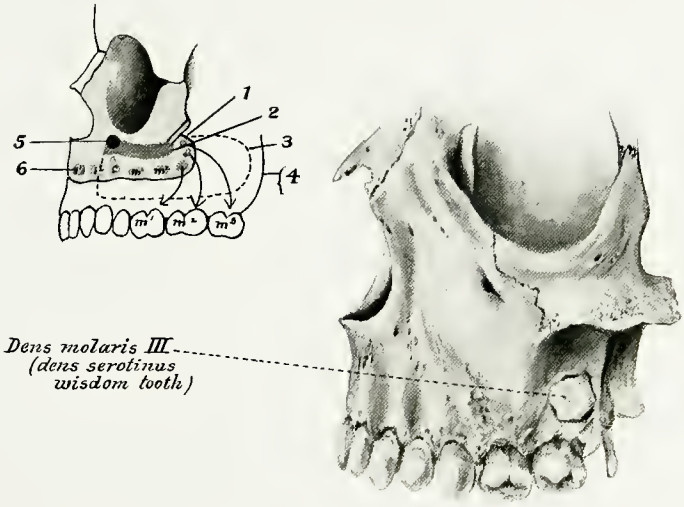

FIG. 90.—An adult maxilla with an impacted or unerupted third molar tooth exposed by the removal of a superficial shell of bone.

The inset (*after Keith*) shows "the manner in which the development of the maxillary antrum affects the size of the palate and position of the molar teeth."

1 = posterior border of maxilla at birth; 2 = maxillary sinus at birth; 3 = maxillary sinus of adult; 4 = posterior border of maxilla of adult; 5 = ostium maxillare; 6 = deciduous teeth at birth.

pushed through the soft structures of the cheek, unless the point were directed well superodorsally (Fig. 87).

In the years of adolescence, as shown by the studies of Keith, Schaeffer and others, the maxillary sinus continues its pneumatizing process until it extends into the various processes of the maxilla. Moreover, as the sinus expands dorsalward the dorsal border of the maxilla which contains the rudiments of the permanent molar teeth, undergoes rotation caudalward, so what was located on the dorsal border ultimately comes

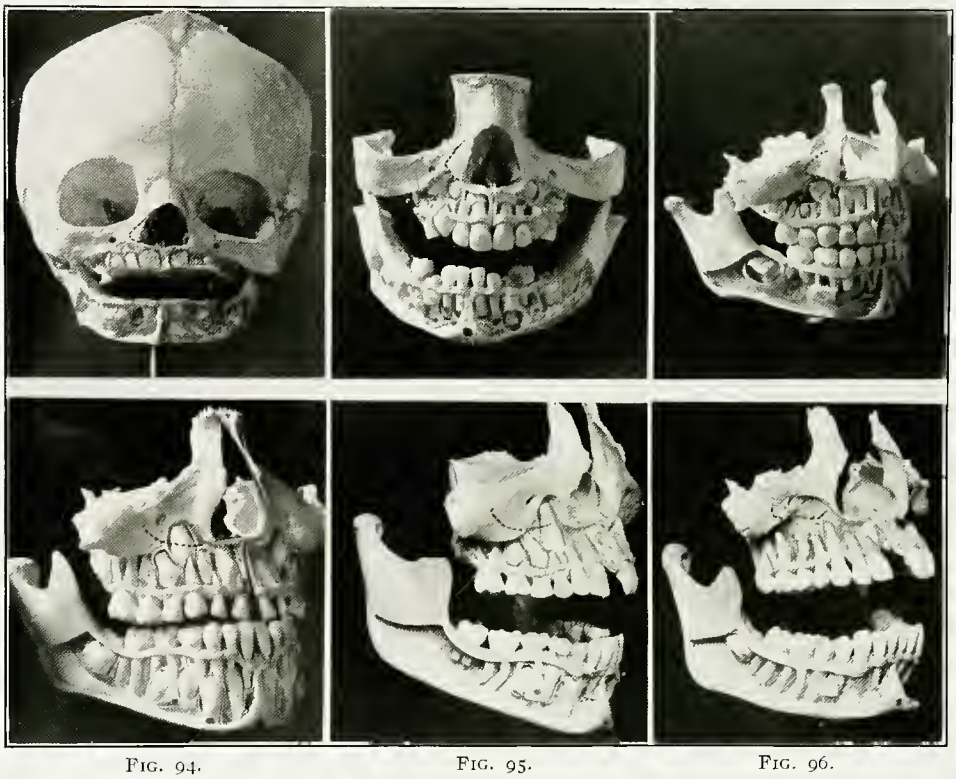

FIG. 91. FIG. 92. FIG. 93.

FIG. 94. FIG. 95. FIG. 96.

FIGS. 91–96.—Photographs of dissections showing the relations of the teeth to the developing maxillary sinus. In each case the sinus is indicated by a dotted line. Fig. 91, from a term child; Fig. 92, from a child aged 18 months; Fig. 93, from a child aged 3 years; Fig. 94, from a child aged 7 years; Fig. 95, from a child aged 9 years; Fig. 96, from a young adult, with all permanent teeth, save the third molar, erupted.

to occupy a position on the alveolar border of the maxilla. If for some reason or other growth and rotation are arrested, the third molar tooth is left on the dorsal border of the maxilla where it may become impacted and call for surgical attention (Figs. 89 and 90).

Ridges, Crescentic Projections and Septa on the Walls of the Maxillary Sinus.—It is very important to note how frequently the walls of the

sinus are found uneven. These irregularities may consist of mere ridges or of different sized crescentic projections. The crescentic projections have been reported occasionally replaced by septa which completely divide the sinus into two cavities, each having its independent opening into the nasal fossa, but not communicating with each other. The smaller ridges are of little consequence and may be omitted from further consideration. The

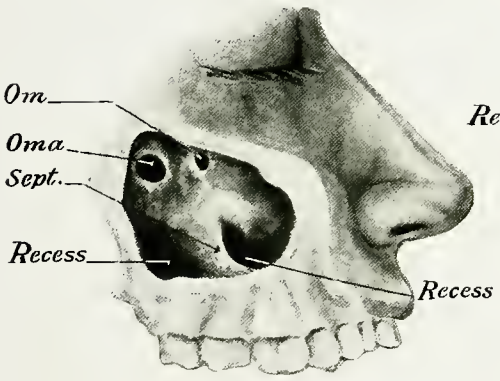

FIG. 97.

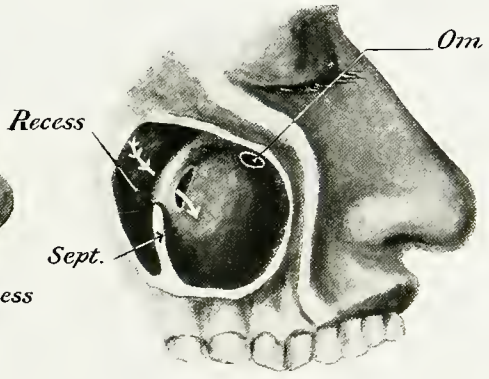

FIG. 98.

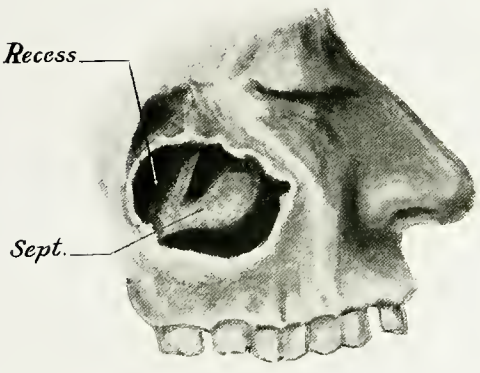

FIG. 99.

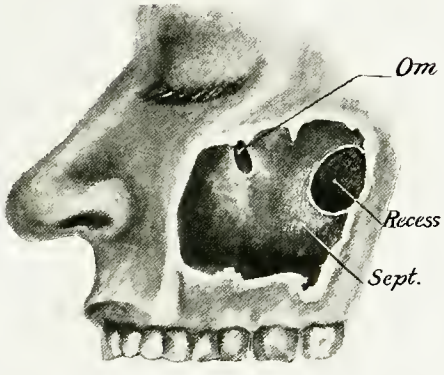

FIG. 100.

FIGS. 97–100.—Drawings of specimens showing incomplete septa with resultant recesses on the walls of the maxillary sinus.

Om = ostium maxillare; *Oma* = ostium maxillare accessorium; *Sept* = septum.

larger ridges and crescentic projections, on the other hand, tend to form pockets and recesses of varying depth within the cavity. The septa, when they exist, are placed either cephalocaudally or ventrodorsally, thus forming either ventral and dorsal, or caudal and cephalic compartments, respectively.

In an examination of 120 adult maxillary sinuses by the author, 58 were found in which the walls showed minor ridges and large crescentic projec-

tions; the remaining 62 presented walls with regular and even mucoperiosteal surfaces. It must be borne in mind that in the 58 positive sinuses quite a number showed mere ridges and can be omitted from further study. The remaining number of the positive group fall, however, into a very important class of specimens. That these crescentic projections offer almost insuperable obstruction at times in attempting to drain the maxillary sinus through an opening in the processus alveolaris or in the meatus nasi inferior, is an anatomic fact of which the operator must be cognizant in empyemas that do not yield readily to treatment. This was repeatedly demonstrated in this study by first filling the sinus with a liquid, then making an opening at some point on the processus alveolaris and draining what would come away. If some of the fluid was retained, allowing for adherence to the mucous membrane, the facial or anterior surface of the maxilla was removed to find where the remaining fluid was lodged. As a rule, the portion of fluid was retained by a recess or recesses on one or more of the sinus walls. At other times a second and even a third opening was made, either through the alveolar border, or through the meatus nasi inferior, before the remaining fluid would come away. If after repeated attempts the fluid could not be located, the ventral wall of the cavity was removed to ascertain the reason for its retention and the fact was thus disclosed that repeated punctures, in some cases, would not reach all of the recesses.

Just what these recesses mean in all cases is difficult to say. Some of them are, of course, formed by elevations caused by tooth fangs, but these as a rule are of minor importance and only occasionally form deep recesses. Others are formed by projections of mucous membrane, which may or may not be caused by crescentic bone projections. Where exceptionally large septa exist the maxillary sinus probably developed from two primary pouches, the intervening wall disappearing in part leaving the larger crescentic projections in the adult sinus. A double pouching of the primitive maxillary sinus was mentioned in a previous paragraph on the development of the cavity (page 101). Unequal resorption of the bone during the growth of the sinus is doubtless the chief cause for the osseous projections on the walls of the cavity, *e.g.*, the sinus growing in the direction of least resistance (Figs. 97, 98, 99 and 100).

Duplication of the Maxillary Sinus.—Duplicate unilateral maxillary sinuses have been recorded by Zuckerkandl, Brühl, Gruber and others. The writer recently made a number of similar observations. Zuckerhandl found that the superior and dorsal of the two sinuses communicated with the superior nasal meatuses and the inferior and ventral cavity

with the usual infundibulum ethmoidale of the middle nasal meatus. The writer finds that the so-called additional or accessory maxillary sinuses in communication with the superior nasal meatus are of frequent occurrence and that they are readily explained from a genetic standpoint. They are clearly *posterior ethmoid cells* which developed beyond the ethmoid field into the body of the maxilla, dorsal to the maxillary sinus proper. Topographically, in the adult, they must, of course, be considered maxillary sinuses. Clinically, too, their classification is more maxillary than ethmoidal, because here one is more concerned with the topography of the sinus than with its genetic history (Figs. 98 and 101).

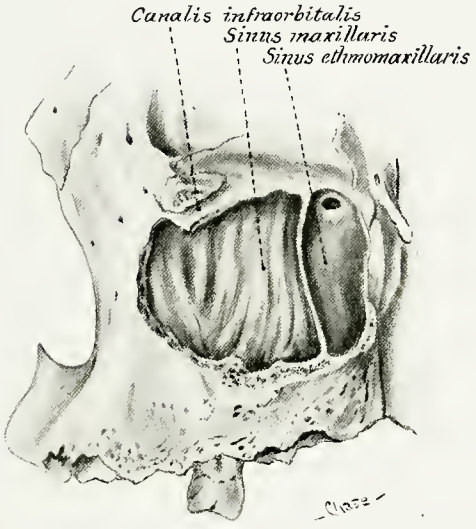

FIG. 101.—A specimen with two entirely separate sinuses in the maxilla. The dorsal sinus (sinus ethmomaxillaris) communicates with the superior nasal meatus and the ventral one with the infundibulum ethmoidale of the middle nasal meatus (see text, page 118).

The aberrant posterior ethmoidal cell in question may occupy but a small portion of the dorsal and superior angle of the body of the maxilla or it may pneumatize more than half of the space more usually occupied by the maxillary sinus. The degree of encroachment on the maxillary sinus is, therefore, dependent upon the size of the ethmoidal cell. Conforming with the size of the encroaching cell, the septum intervening between the cell and the maxillary sinus is variously placed; now in the vertical and sagittal plane, again in the oblique and semi-coronal plane. The septum may, therefore, extend from the alveolar border of the maxilla (floor of the maxillary sinus) to the infraorbital wall (roof of the maxillary sinus), or from the dorsal wall of the sinus to the roof of the sinus.

Clinically, an intelligent appreciation of this not infrequent anatomic type of the maxillary field is important. The dorsal compartment of the maxillary sinus (aberrant posterior ethmoidal cell), often of considerable size, when diseased would in all likelihood give the typical symptoms of an involvement of the maxillary sinus. The usual routes of draining the maxillary sinus by way of the inferior nasal meatus, through the alveolus, or through the canine fossa, would, more than likely, lead into the unaffected maxillary sinus proper and with negative findings. Of course, endonasal inspection would assist the operator in the diagnosis, as would also the skiagram.

These aberrant posterior ethmoidal cells, topographically maxillary, practically always communicate with the superior nasal meatus. The author observed one specimen in which a cell in communication with the first supreme nasal meatus extended into the maxilla and encroached upon the maxillary sinus.

The supernumerary maxillary sinus described by Brühl in communication with the inferior nasal meatus is difficult of genetic explanation since no paranasal sinus develops from this meatus and in the adult none communicates with it. In all likelihood the ostium of communication in Brühl's case was established in a manner similar to the formation of the ostium maxillare accessorium and the duplicate sinus grew from one of the usual points (see page 101). Gruber claims to have found a complete division of the maxillary sinus in $2\frac{1}{2}$ per cent. of cases. This is in approximate agreement with the author's studies if the posterior ethmoidal cells which so commonly grow into the maxilla from the dorsal and caudal portion of the superior nasal meatus are classed as maxillary sinuses. Indeed, it must be recalled that the maxilla regularly aids in completing the osseous boundaries of certain ethmoid cells. These are topographically ethmomaxillary, genetically ethmoidal.

At times the maxillary sinus grows into the hard palate by an extension of the alveolar recess between the plates of the palate in the formation of the so-called *recessus palatinus* (Fig. 85). While the latter recess is usually in wide communication with the maxillary sinus, it is plausible to think that a narrow channel of communication may through disease become obliterated and the recess thus isolated an individual chamber. One readily sees how these palatine recesses may become cysts in the hard palate. Meyer[1] describes "a unique supernumerary paranasal sinus directly above the superior incisors." He was not certain of its communication, and its genesis is difficult of explanation in the absence of exact

[1] Jour. Anat. and Phy., Vol. 48, 3rd series, Vol. 9, 1914.

knowledge concerning its communication. Its total size was 16 by 13.5 by 22 mm. In this connection one naturally thinks of the recessus palatinus previously referred to and to dentigerous cysts. Indeed, the Y-shaped incisive foramen with the contained remnants of the nasopalatine canals at times give rise to epithelially-lined cells or cysts. If one recalls that the nasopalatine canals at one time in the embryo connect the inferior nasal meatuses with the mouth cavity it is readily understood why cells arising

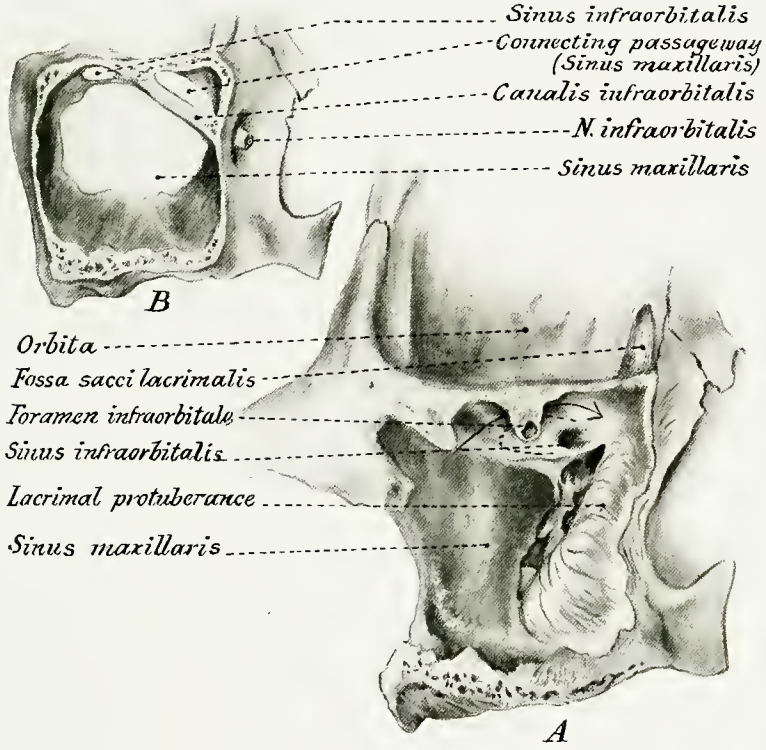

FIG. 102.—In *A*, the facial wall of the maxillary sinus has been removed thereby exposing the median or nasal wall of the sinus. An extremely prominent lacrimal proturberance presents. Moreover, it should be noted that there is a blindly-ending recess in the roof of the maxillary sinus (sinus infraorbitalis) and that the infraorbital canal courses from the infraorbital wall to the facial wall of the maxillary sinus, leaving a connecting passageway over the canal and contained nerve (indicated by the arrow in the larger figure).

The inset *B*, represents a saggital section just lateral to the infraorbital foramen.

from them may communicate in later life with either the inferior nasal meatus or the mouth cavity. However, should both extremities of the nasopalatine canal become obliterated and the intervening part remain patent, it could readily give rise to a cyst. Of course, unusual and anomalous structures at times develop and Meyer's case may have represented

a freakish accessory nasal sinus which developed from the inferior nasal meatus. If so, the case is unique so far as the writer knows.[1]

The Size of the Maxillary Sinus.—The maxillary sinus varies greatly in size in different individuals. Moreover, there may be considerable asymmetry on the two sides of the same individual. The belief that all old people have large sinuses is very fallacious, as is also the statement that all females have smaller sinuses than males (tables C, D, and E).

The investigations of Zuckerkandl,[2] in which the writer concurs, have shown that enlargement of the maxillary sinus is produced by:

(*a*) Hollowing out of the processus alveolaris of the maxilla (recessus alveolaris) (Fig. 85).

(*b*) Excavation of the floor of the nasal fossa by a pushing of the recessus alveolaris between the plates of the palatum durum (recessus palatinus) (Fig. 85).

(*c*) Extension of the maxillary sinus into the frontal process of the maxilla (recessus infraorbitalis)[3] (Fig. 175).

(*d*) Hollowing out of the processus zygomaticus of the maxilla (recessus zygomaticus).

(*e*) Extension to, and appropriation of an air cell within the processus orbitalis of the palate bone.

To these should be added, according to the author's findings:[4]

(*f*) Extreme hollowing out of the body of the maxilla in all directions, thus causing the sinus walls to be thin and the recesses all markedly developed (Fig. 174).

(*g*) The rarer condition in which the lateral nasal wall is bulging toward the cavum nasi.

(*h*) The extension of the recessus zygomaticus of the sinus maxillaris into the maxillary border of the zygomatic bone.

The sinus is made smaller, on the other hand, by:

(*a*) Deficient absorption of the cancellated bone on the floor of the sinus.

[1] Since concluding the above discussion the author observed a specimen in which a goodly sized epithelially-lined cavity existed in the line of the original nasopalatine canal. It was a bl nd cavity and communicated neither with the buccal cavity nor the nasal fossa. Careful study of it strongly indicated that it was a remnant or persistent portion of the embryonic nasopalatine canal.

[2] Anatomie der Nasenhöhle, Leipzig, 1893.

[3] The term "recessus prelacrimalis" is, however, more applicable for this recess. The term "recessus infraorbitalis" should be retained for the occasional extension of the maxillary sinus into the infraorbital wall of the maxilla (see Fig. 102). Indeed, the term "recessus frontalis" is more suggestive; however, is liable to be confused with the recessus frontalis of the middle nasal meatus.

[4] Schaeffer: The Sinus Maxillaris and Its Relations in the Embryo, Child and Adult Man, Amer. Jour. Anat., Vol. 10, No. 2, 1910.

(*b*) Encroachment of the ventral wall of the cavity (Fig. 87).
(*c*) A deep fossa canina (Fig. 87).
(*d*) Thick sinus walls.
(*e*) Excessive lateral bulging of the nasal wall.
(*f*) A combination of the above conditions.
(*g*) Imperfect dentition.

The thickness of the sinus walls varies from 5 to 8 mm. and down to that of a papery delicacy. The statement that all large cavities have thin walls and small cavities invariably thick walls does not hold in all cases. The smallest sinus measured in this series had the thinnest walls, the small size of the cavity being in part due to the marked simultaneous approximation of the ventral and medial walls.

The size of the maxillary sinus is best determined by a series of measurements, viz.:

1. Dorsocephalic diagonal.
2. Ventrocephalic diagonal.
3. Cephalocaudal (height).
4. Ventrodorsal (length).
5. Mediolateral (width).

These several measurements are determined thus:

1. The dorsocephalic diagonal, from the most dorsal and lateral part of the sinus floor diagonally across the base or median wall of the sinus, to the most medial and cephalic part of the recessus infraorbitalis.

2. The ventrocephalic diagonal, from the most ventral and medial part of the recessus alveolaris diagonally across the base of the sinus to the most lateral and cephalic point of the cavity.

3. The cephalocaudal, from the roof or infraorbital wall of the sinus to the sinus floor (always using uniform points).

4. The ventrodorsal, from the most ventral point of the cavity midway between the roof and the floor, to the dorsal wall.

5. The mediolateral, from the base midway between its most ventral and dorsal points to the processus zygomaticus of the maxilla (in some cases this extends into the maxillary border of the zygomatic bone, due to the extension of the recessus zygomaticus of the maxillary sinus into this bone).

The ventrodorsal distance is especially affected by the degree of approximation of the ventral wall of the sinus; the cephalocaudal by the degree of pneumatization of the processus alveolaris of the maxilla; the mediolateral by the degree of encroachment of the lateral nasal wall; the ventrocephalic diagonal by the extent of the recessus alveolaris; and

the dorsocephalic diagonal by the extent of the recessus infraorbitalis. Of course, there are other contributing factors to shorten or lengthen these distances, but these are the primary factors especially affecting the several measurements.

In order that the measurements of the maxillary sinus may be of most value, it is necessary to compare the two sinuses of the same individual; to compare them with the respective sinuses of another individual; also to consider the age and the sex.

The following tables, C and D, are appended for comparison as indicated above:

A careful examination of tables C and D shows conclusively that the maxillary sinus has a rather wide range of variation. Moreover, the tables indicate that, in the adult, age does not have any bearing on the size of the cavity. Although the maxillary sinus averages slightly larger in the male than in the female, sex affects the size of the cavity but slightly.

Table E indicates the variation range found in the study of a series of specimens. It will be noted that the smallest cavity is that of an old man aged 70 years, while the largest cavity is that of an old man aged 77 years. The same table shows that the cavity of a young adult, aged 21 years, is a close second to the largest sinus found in the entire series.

TABLE C.—MAXILLARY SINUS

Male—Measurements in Millimeters

Age	Side	Ventrodorsal	Mediolateral	Cephalocaudal	Dorsocephalic diagonal	Ventrocephalic diagonal
54	right	26	15	20	30	26
	left	30	16	22	32	26
68	right	40	22	50	50	50
	left	35	24	35	45	50
36	right	32	32	40	40	38
	left	30	18	40	41	41
65	right	30	15	30	33	30
	left	25	15	25	35	36
55	right	40	25	40	45	45
	left	40	22	38	36	45
57	right	40	21	32	50	38
	left	32	25	30	32	43
71	right	35	22	45	45	40
	left	40	18	35	40	45
59	right	40	22	33	45	45
	left	40	35	40	50	45
79	right	30	30	35	41	40
	left	43	20	30	41	37
55	right	31	24	30	30	38
	left	32	25	35	40	40

TABLE D.—MAXILLARY SINUS

Female—Measurements in Millimeters

Age	Side	Ventrodorsal	Mediolateral	Cephalocaudal	Dorsocephalic diagonal	Ventrocephalic diagonal
68	right	35	35	35	40	30
	left	40	16	30	43	36
52	right	35	21	30	40	40
	left	35	24	28	38	45
53	right	40	25	30	60	42
	left	33	30	45	45	46
47	right	36	26	25	37	37
	left	37	28	35	35	37
73	right	33	24	31	38	40
	left	37	24	37	30	42
50	right	33	17	30	35	40
	left	33	22	33	38	34
35	right	30	18	32	30	35
	left	30	21	30	30	40
39	right	34	25	33	32	35
	left	33	22	33	32	24
72	right	38	25	38	32	34
	left	35	23	38	33	35
52	right	35	21	30	40	36
	left	35	21	32	38	35

TABLE E.—MAXILLARY SINUS

Measurements in Millimeters

Age	Side	Sex	V-d	M-l	C-c	D-c D	V-c D
70	R	M	15	12	21	21	18
70	L	M	16	12	21	21	20
35	L	M	22	20	30	31	25
54	L	M	25	15	22	32	27
54	R	F	26	15	20	30	26
60	L	M	30	20	22	38	25
52	R	F	35	25	30	37	38
59	L	M	40	22	32	35	45
21	R	M	46	33	26	50	50
77	L	M	47	40	50	57	60

The following may be given as average measurements of the adult maxillary sinus, based on the measurements of 150 specimens:

1. Dorsocephalic diagonal . . . . . 38.0 mm.
2. Ventrocephalic diagonal . . . . . 38.5 mm.
3. Cephalocaudal . . . . . 33.0 mm.
4. Ventrodorsal . . . . . 34.0 mm.
5. Mediolateral . . . . . 23.0 mm.

Due to the great differences in the several measurements, the capacity of the sinus in different individuals must also differ. The range in capacity, of the sinuses studied to ascertain this fact, was from 9.5 cc. to 20 cc., with an average of 14.75 cc.

The conditions which produce the varied differences in the dimensions of the maxillary sinus may be readily ascertained. Take, for example, the following two cases which show a marked difference in the mediolateral plane with an inversion of the other measurements:

Specimen	V-d, mm.	M-l, mm.	C-c, mm.	D-c D, mm.	V-c D, mm.
a	30	18	40	41	41
b	35	35	35	40	30

In specimen "a" the lateral nasal wall was markedly bulging toward the maxillary sinus. In consequence of this encroachment the mediolateral distance was greatly lessened. In specimen "b" the recessus alveolaris was poorly developed, hence the short ventrocephalic diagonal in comparison with the respective measurement in specimen "a." These specimens show that even though a sinus may greatly exceed another in one of its measurements, it may be exceeded in size in its other planes.

Again, there may be a great difference in the ventrodorsal distance. This means a marked inpushing or depression of the ventral or facial wall of the sinus on the one hand and a shallow fossa canina with a lessened encroachment on the other. Thus:

Specimen	V-d, mm.	M-l, mm.	C-c, mm.	D-c D, mm.	V-c D, mm.
c	25	15	25	35	36
d	43	20	30	41	37

If the body of the maxilla is pneumatized to a marked degree in all directions the measurements will be correspondingly lengthened. When the hollowing out process has not been carried far, and when associated with some of the above-mentioned conditions, the measurements will be markedly lessened. Thus:

Specimen	V-d, mm.	M-l, mm.	C-c, mm.	D-c D, mm.	V-c D, mm.
e	47	40	50	57	60
f	16	12	21	21	20

These few examples show how anatomic conditions affect the measurements of the maxillary sinus. It appears reasonable, therefore, that, by examination of the ventral surface of the maxilla and the lateral nasal wall, the size of the sinus may be approximately determined and the teeth relations judged with fair accuracy. It does not necessarily follow, however, because the ventral and median walls of the sinus are closely approximated, that the capacity of the maxillary sinus is markedly lessened. Such sinuses may have marked infraorbital recesses and the processus alveolaris may be hollowed out toward its dorsal termination. In this manner compensation may be made for the marked encroachment of the ventral and median walls of the sinus. It remains, however, that in the vast majority of cases where these walls are simulatneously bulging in the cavity the sinus is correspondingly reduced in size and the canine and premolar teeth not in direct relation to the sinus.

The Maxillary Ostium (ostium maxillare).—The primitive maxillary pouch is in relationship with the *processus uncinatus*, the *infundibulum ethmoidale*, the *hiatus semilunaris*, and the *bulla ethmoidalis*. The location of the maxillary ostium of the adult corresponds to the place of the primitive maxillary pouch. The pouch gradually develops into the pyramidal-shaped cavity of the adult, leaving the place of communication with the infundibulum ethmoidale at the point of primary evagination. It is, therefore, obvious that the above structures, which in the embryo bore so close a relation to the anlage of the maxillary sinus, must bear even more important relations to the maxillary ostium of the adult sinus. It is, therefore, essential to recall the regional anatomy of the communication of the maxillary sinus with the nasal fossa.

On raising or removing the middle nasal concha, in the adult, a rounded elevation—the bulla ethmoidalis—is seen. As stated elsewhere, the latter is directed caudally and ventrally. Immediately beneath the bulla is the well-defined curved margin of the processus uncinatus of the ethmoid bone. Between these structures is a narrow slit or semilunar cleft—the *hiatus semilunaris*—from 15 to 20 mm. long. The semilunar hiatus is an important opening, since it is the communication between the meatus nasi medius and the gutter-like infundibulum ethmoidale. The bulla ethmoidalis varies considerably in size. At times it is feebly developed, again may assume relatively large proportions. The size of the bulla greatly influences the width of the hiatus semilunaris (Fig. 161).

It is easy to conclude what effect these conditions have on the maxillary ostium directly and on the maxillary sinus indirectly. In some cases the cleft of communication between the maxillary ostium and the meatus

nasi medius is practically shut off, while in the others a freer communication exists. It must be remembered, however, even though the bull touches the free margin of the processus uncinatus and thereby greatly narrows the hiatus semilunaris, that the infundibulum ethmoidale may be of average dimensions. This is an important fact and must be borne in mind when considering the fronto-maxillary relations and the possibility of drainage from the frontal region into the maxillary sinus (see page 160).

The *processus uncinatus* with its covering of mucous membrane projects inferiorly and dorsally. By its free superior border it forms the caudal boundary of the hiatus semilunaris. This process not infrequently

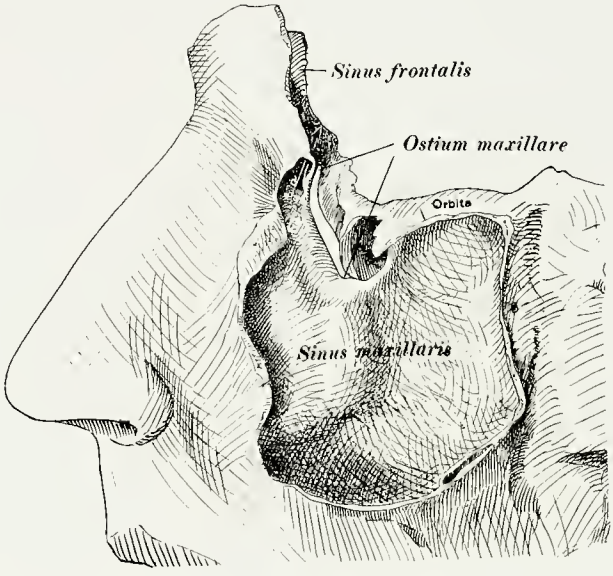

FIG. 103.—A dissection with the medial or nasal wall of the maxillary sinus exposed from the sinus side. Note especially the large and elongated ostium maxillare and its intimate relation to the frontal sinus. Obviously in such cases the frontal sinus drains almost wholly into the maxillary sinus (see text, page 160).

terminates dorsally in what may be termed two roots: The *inferior root* passes toward the cephalic edge of the concha nasalis inferior, while the *superior root* curves superiorly behind the dorsal termination of the bulla ethmoidalis and causes the infundibulum ethmoidale to end in a pocket (Fig. 127). This fact is of extreme importance because the pocket is so situated that it will direct fluid or infectious materials coming to the dorsal end of the infundibulum ethmoidale into the maxillary sinus, via the maxillary ostium which is in the immediate location.

The *infundibulum ethmoidale* is a groove or gutter situated upon the lateral nasal wall. It is bounded cephalically by the caudal surface of

the *bulla ethmoidalis* throughout the greater part of its extent, save ventrally and superiorly where the bulla is replaced by some *anterior ethmoidal cells*. The caudal and mesial boundary of the groove is formed by the lateral surface of the *processus uncinatus*. The infundibulum ethmoidale communicates with the meatus nasi medius through the *hiatus semilunaris* and, as stated elsewhere, either ends in a pocket or loses its depth gradually by merging with the meatus nasi medius proper (Fig. 125). The cephalic and ventral end of the infundibulum may terminate blindly, dilate into an air cell, or be continuous with the nasofrontal duct. The lateral wall of the infundibulum is formed partly by mucous membrane. The depth of the gutter-like infundibulum ethmoidale, *i.e.*, the distance from the free border of the processus uncinatus to the floor of the groove, varies from 1 to 12 mm., with an approximate average of 5 mm.

The maxillary sinus communicates indirectly with the meatus nasi medius by means of a series of openings—(1) the maxillary ostium which pierces the superior and ventral part of the base of the sinus to open into (2) the infundibulum ethmoidale, thence via (3) the hiatus semilunaris into the meatus nasi medius. It must be clearly kept in mind that the ostium is located in the superior part of the sinus and that it opens into the infundibulum ethmoidale and not into the hiatus semilunaris, as many writers say. The maxillary ostium is located either in the most dependent part of the infundibulum or in the lateral wall of this channel, and varies from 1 to 12 mm. in distance from the hiatus semilunaris. The distance is dependent upon the width of the processus uncinatus and the resultant depth of the infundibulum ethmoidale at this point.

The maxillary ostium may be round, but as a rule is either oval or elliptical. In a series of 110 cases examined by the writer it had a great range of dimensions, varying from 1 to 22 mm. in length and from 1 to 6 mm. in width. In cases where the ostium reaches considerable size it may entirely replace the lateral wall or floor of the infundibulum ethmoidale, thus forming a long slit-like communication between the maxillary sinus and the infundibulum ethmoidale (Figs. 77 and 103).

Duplication of the Maxillary Ostium.—In a previous paragraph mention was made of the double pouching of the primary maxillary sinus. Distal fusion of two pouches would leave the points of evagination as the adult ostia maxillaria, and the cavity proper would appear as a single chamber. Most duplications of the ostium maxillare proprius are, however, doubtless caused in a manner similar to the establishment of the ostium maxillare accessorium; that is, by the attenuation and ultimate rupture of the mucous membrane in the neighborhood (undefended region

of the middle nasal meatus, page 92). Disease may be the underlying factor in some instances. The duplicated maxillary ostium is always located dorsal to the regular aperture and in the dorsal end of the infundibulum ethmoidale. It varies much in size.

The Accessory Maxillary Ostium (ostium maxillare accessorium).—The accessory maxillary ostium is, as a rule, situated in the membranous portion of the lateral wall of the middle meatus, a short distance above the cephalic and attached border of the inferior nasal concha at about the junction of its middle and posterior thirds. In some instances it is located immediately dorsal to the infundibulum ethmoidale—occasionally extending into the latter. The accessory ostium is usually single, but may be duplicated. Rarely three accessory apertures are present in this portion of the middle meatus. The aperture must not be confused with the duplication of the maxillary ostium previously referred to.

Nathaniel Highmore, who apparently was the first anatomist to describe the maxillary sinus, does not mention the accessory ostium. Giraldès in 100 cadavers found it "acht bis zehn Mal." Zuckerkandl reports it present "in jedem neunten bis zehnten Falle." Chiari and Hajek found an accessory ostium in every fifth case. Turner found it four times in nine dissections. The fourth annual report of the committee of collective investigation of the Anatomical Society of Great Britain and Ireland states that in an examination of 152 specimens 17.6 per cent. showed accessory maxillary ostia. Warren B. Davis[1] in an examination of 114 lateral nasal walls from cases between 4 and 24 years of age reports accessory ostia in 15 per cent.; moreover, reports one instance in a child just past four years of age. The frequence of occurrence as reported by Davis can hardly be compared with other reports since accessory ostia are not common before the fifteenth year. In a former paper[2] the writer reported the accessory maxillary ostium present 35 times out of 80 adult specimens examined, a percentage of 43.75. Three of the specimens had two accessory ostia. In another study[3] of 125 adult specimens the writer reported accessory ostia in 42.4 per cent. of cases, three of the specimens presenting two such apertures. In a third series, not previously reported, of 90 adult specimens, the writer found 37 per cent. with accessory ostia.

J. A. Giraldès[4] was apparently the first to consider this opening from a developmental point of view. He came to the conclusion "dass in allen

[1] Nasal Accessory Sinuses, Philadelphia, 1914.

[2] Schaeffer: Amer. Jour. Anatomy, Vol. 10, 1910.

[3] Schaeffer: The Ostium Maxillare Accessorium, Twenty-sixth Session American Association of Anatomists, December, 1910.

[4] Archiv f. path. Anat. und Physiologie und f. klinische Medicin, Bd. 9, 1856.

Fallen, wo diese abnorme Oeffnung besteht sie immer das Product eines pathologischen Vorganges und durch eine wirkliche Perforation zu Stande gekommen ist." He considered the aperture much less common than it is, thinking it present in only 8 or 10 per cent. of instances. Giraldès bases his pathologic theory on the fact that he had the privilege of following the "Entwicklungsphasen von der Verdunnung der Schleimhaut des Ganges bis zur volständigen Durchbohrung." Zuckerkandl corroborates the

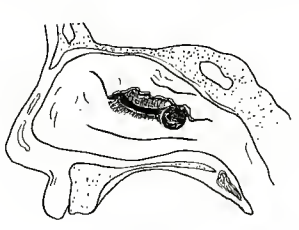

FIG. 104.

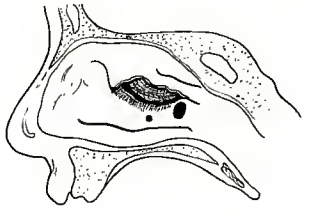

FIG. 105.

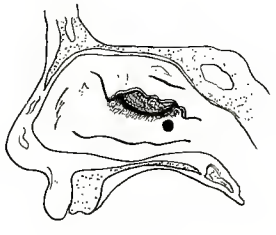

FIG. 106.

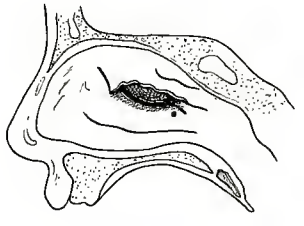

FIG. 107.

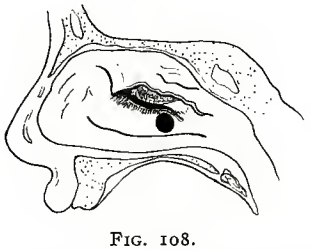

FIG. 108.

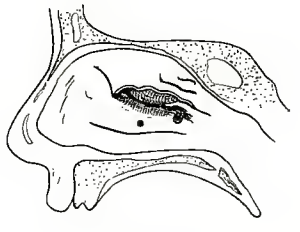

FIG. 109.

FIGS. 104–109.—Diagrams of the lateral nasal wall with the concha nasalis media partly cut away. Note the positions and relative sizes of the ostium maxillare accessorium, indicated by the deep black circles. See text, page 130.

thinning of the mucous membrane, but does not hold to the pathologic theory. The latter author has seen some cases where an accessory aperture was caused by the gradual wearing of a "zugespitzer Hakenfortsatz der Nasenscheidewand," which finally resulted in an opening on the lateral wall of the middle meatus.

While some accessory apertures are obviously due to a pathologic process as suggested by Giraldès, and others caused in a mechanical manner by spurs on the nasal septum as suggested by Zuckerkandl, we

must certainly look elsewhere in most cases for the genesis of this very common aperture.

The author agrees that there is a thinning of the mucous membrane in the position of the accessory maxillary ostium, but believes the explanation for this is found in the development of the maxillary sinus. In the fetus and infancy the walls of the sinus are relatively thick. The sinus cavity increases by the simultaneous growth of the sac and the resorption of surrounding tissue, these processes taking place *para passu* with the growth of the face. In this manner the sinus walls become thinner and thinner up to a limit as age advances. The thinning apparently progresses unevenly, as is evidenced by the very uneven walls of many adult cavities. On the base or median wall of the cavity there is an area that is in time composed merely of two layers of abutting mucous membrane: one the mucous membrane of the middle meatus, the other the mucous membrane of the maxillary sinus. These two layers with no intervening bone (*the undefended area*, Fig. 73) offer very little resistance to the growing maxillary cavity. In time they become so thinned out and attenuated that ultimately an opening is formed, thereby establishing the ostium maxillare accessorium. This process reminds one of the early thinning and attenuation and ultimate rupture of the two layers of abutting epithelium—the bucconasal membranes—in the establishment of the primitive choanæ (page 9).

If the above hypothesis as to the genesis of the ostium maxillare accessorium is well grounded one would not expect to find the aperture in fetuses or in young infants. Indeed, one would not expect the incidence of occurrence to be frequent before the fifteenth year; that is, when the maxillary sinus passes into the adult stage. Moreover, one would look for its appearance, especially in the adult, after the walls of the maxillary sinus have been sufficiently thinned out by the enlargement of the cavity. In support of the above the writer has been unable to find an accessory maxillary ostium in the fetus and in the young child, but found it very frequently between the ages of 13 and 90 years. Symington[1] says: "In children I have never found more than one aperture, viz., that in the infundibulum." Davis,[2] on the contrary, found an accessory opening between the fourth and fifth year.[3]

[1] The Anatomy of the Child, Edinburgh, 1887.

[2] Loc. cit.

[3] Since the completion of the manuscript on the maxillary sinus the author observed in a post-mortem on a child aged 11 years a large bilateral accessory maxillary ostium. Careful examination showed the mucous membrane of the nasal fossæ and paranasal sinuses to be in a good state of health (Fig. 153).

The writer has, therefore, come to the conclusion that the ostium maxillare accessorium is, in most instances, established by the developing maxillary sinus; the growth of the sinus causing the two layers of abutting mucous membrane to become thinned and attenuated, resulting ultimately in an additional aperture in very many adult noses. Some of the accessory ostia are, doubtless, due to a pathologic process, and others produced in a mechanical manner by septal spurs. It is, of course, difficult to give the exact percentages in the classification of causes. Indeed, it matters little. The fact remains that the accessory maxillary ostium, a direct communication between the maxillary sinus and the middle nasal meatus, is of very frequent occurrence, often of goodly size and more advantageously placed as a drainage and exploring point of the maxillary sinus than is the regular maxillary ostium which is located farther cephalically and in the depth of the narrow infundibulum ethmoidale. The writer would urge that operators utilize this accessory ostium more frequently in irrigations of the maxillary sinus, moreover would point out that the incidence of occurrence, as given by Giraldès and so commonly referred to in text-books, is archaic and far too low.

Concluding Considerations.—Valuable information may be learned of the size, contour and relationships of the adult maxillary sinuses by the use of the X-rays. The ventrodorsal (anteroposterior) skiagram usually clearly delineates the position of the lateral nasal walls and the degree of development of the palatal recess of the maxillary sinus. Moreover, the relationship of the sinus floor to the nasal floor is indicated, as is also the degree of pneumatization of the alveolar process (alveolar recess of the maxillary sinus). Such information is, doubtless, of some value in anticipation of operative procedures, either by the endonasal, alveolar, or canine fossa approaches. Inspection itself not infrequently gives the experienced observer a fairly definite clue as to the type of maxillary sinus before him. However, the skiagram is an invaluable supplement to inspection. As mentioned elsewhere (page 114), the simultaneous approximation of the medial (lateral nasal wall) and ventral (facial) walls of the maxillary sinus almost always precludes the possibility of a palatal recess and of an alveolar recess in the ventral third of the alveolus. A deep canine fossa and a lateral bulging of the lateral nasal wall are, of course, readily determined by inspection; the skiagram confirming this by showing a restricted maxillary sinus in its ventrodorsal diagonal and fewer teeth in true relationship to the sinus floor (usually the second and third molars only).

One must always recall the possibility of dealing with a maxillary sinus incompletely divided by septa into sub-compartments and that some

of these may be of considerable depth. Moreover, that the compartment opened into may not establish drainage for the entire sinus. Indeed, the infection may be in a posterior ethmoidal cell which has pneumatized a goodly portion of the body of the maxilla. In most cases the normal maxillary sinus would be explored, with negative results (see page 118, Figs. 98 and 101).

The location of the ostium of the maxillary sinus, in the depth of the ethmoidal infundibulum, would seem to preclude the possibility of exploring the maxillary sinus through its normal aperture. In this connection it is well to recall the structures in relation to the maxillary ostium; that is, the ethmoidal bulla, the uncinate process, the semilunar hiatus, and the ethmoidal infundibulum. The bulla when large practically shuts off the semilunar hiatus or entrance into the infundibulum. An examination of a large series of specimens leads the author to believe that it is impossible clinically in the vast majority of cases to sound the maxillary sinus through its normal ostium (Figs. 128 and 197). This conclusion based upon anatomic facts is in conformity with the clinical findings of Cryer,[1] Skillern[2] and many others. In those cases where successful sounding of the maxillary sinus through the normal aperture is reported it is more than likely that an artificial opening was made into the maxillary sinus through the *undefended* floor and lateral wall of the ethmoidal infundibulum. It is only fair to state, however, that at times the ethmoidal bulla is small and the uncinate process narrow and probably turned nasalward with a resultant shallow and more or less wide-mouthed ethmoidal infundibulum (Fig. 125). It is in such cases that the operator succeeds in exploring or sounding the maxillary sinus through its normal aperture—the ostium maxillare.

Perforation of the lateral wall of the inferior nasal meatus for purposes of exploring or medicating the maxillary sinus seems to be the preferred route by clinicians. One must, however, always bear in mind that the floor of the maxillary sinus is in the majority of cases at a level inferior to that of the inferior nasal meatus and that an artificial aperture by way of the inferior nasal meatus does not give the most dependent drainage for the maxillary sinus.

The frequency of the accessory maxillary ostium connecting the middle nasal meatus and the maxillary sinus directly should not be forgotten when attempting to sound the sinus by way of normal apertures

[1] Internal Anatomy of the Face, Philadelphia and New York, 1916.

[2] The Catarrhal and Suppurative Diseases of the Accessory Sinuses of the Nose, Philadelphia and London, 1916.

(see page 130). The accessory aperture is frequently of goodly size and is probed with much greater ease than is the constant aperture in the depth of the ethmoidal infundibulum.

Profile skiagrams of the maxillary sinus are frequently confusing in that it is difficult in the healthy state to distinguish between the right and left sinuses in the picture. The ventrodorsal view is to be preferred.

When subjecting the maxillary sinus, filled with fluid, to pressure the undefended part of its medial wall (pars membranacea) yields and bulges into the middle nasal meatus. Clinically, it is stated that such bulging is almost always pathognomonic of an empyema of the sinus in which the normal aperture is either blocked or, because of its size and faulty anatomic location, leads to deficient drainage.

IV—THE FRONTAL SINUS

CHAPTER IV

THE FRONTAL SINUS

The Fetal Stage

The nasofrontal region is genetically an outgrowth from the ventral and cephalic end of the middle nasal meatus operculated by the middle nasal concha (middle turbinated bone). The mucosa of this part of the middle meatus is, therefore, the proton of what subsequently becomes the *recessus frontalis* (a term very suggestive, and to be preferred to the recessus conchalis used by others) of the middle nasal meatus (early in evidence) and derivatives therefrom. The recessus frontalis in turn is the rudiment of the *sinus frontalis* and certain of the anterior group of the *cellulæ ethmoidales* (also called cellulæ frontales by Killian, Onodi and others).

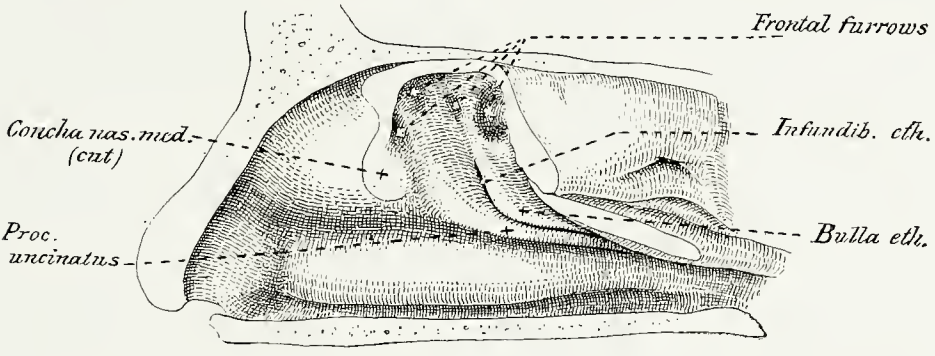

FIG. 110.—A dissection of the frontal recess of a term fetus showing the early frontal furrows or pits; *e.g.*, rudiments of anterior ethmoidal cells and potential rudiments of the frontal sinus. × 1.5.

As early as the end of the third or beginning of the fourth month of embryonic life, one sees evidence of a beginning extension of the middle nasal meatus in a ventrocephalic direction. This early extension is the beginning of the recessus frontalis, and is, strictly speaking, the first step in the formation of the frontal sinus and certain of the anterior group of ethmoidal cells. For some time the lateral wall of the recessus frontalis is even and unbroken and gives no evidence of the later configuration and complexity which characterizes the region in the adult nose. Coronal sections and transections of the recessus frontalis of a 4-month fetus show the lateral nasal plate of cartilage thickened at certain points. These thickened cartilaginous areas—the precursors of the folds or

accessory conchæ which later configure the lateral wall of the recessus frontalis—vary in number and are for a period low and inconspicuous and do not throw the nasal mucosa into relief.

Upon examining the recessus frontalis in the late fetus, one finds a variable number of low accessory conchæ on its lateral wall (Figs. 35 and 36). The folds, with the cartilaginous skeleton now partly ossified, are at this time sufficiently developed to throw the nasal mucosa into relief. Between the folds are found pits or furrows, the positive growth or outpouching of which aids materially in making more prominent the folds. It is appropriate to speak of the latter as accessory or hidden frontal folds or conchæ and the pits as frontal furrows of the middle nasal meatus. As mentioned above, there is no constancy in the degree of differentiation and development of the frontal folds and furrows. The number varies from a complete absence to four or five. In some instances, therefore, the recessus frontalis remains a simple blind outgrowth from the middle nasal meatus without configuration of its lateral wall (Fig. 111.)

The processus uncinatus and the folds composing the bulla ethmoidalis should likewise, as previously stated, be considered accessory conchæ of the middle nasal meatus (analogues and homologues of the frontal conchæ), and the infundibulum ethmoidale and the suprabullar furrow as accessory meatuses or furrows of the middle nasal meatus (analogues and homologues of the frontal furrows).

The frontal furrows or pits early evaginate and form certain of the anterior group of ethmoidal cells or the so-called frontal cells. Semicoronal sections through the recessus frontalis show these early cells. When the latter cells are followed in serial sections toward the recessus frontalis, they are shown to be extensions or outpouchings of the frontal furrows and in communication with the recess (Figs. 147 and 148). Some of the ethmoidal cells having their genesis in frontal pits remain diminutive and ethmoidal in topography, while others grow to considerable size and often develop beyond the confines of the ethmoid bone.

It is a well-established fact that the frontal sinus develops variously: (1) by a direct extension of the whole recessus frontalis, (2) from one or more of the anterior group of cellulæ ethmoidales which have their point of origin in frontal furrows, and (3) occasionally from the ventral extremity of the infundibulum ethmoidale, either by direct extension or from one of its cellular outgrowths. Indeed, the frontal sinus is frequently unilaterally or bilaterally present in duplicate or triplicate, indicating a genesis from more than one of the aforementioned areas. The frontal sinus is, embryologically speaking, in many instances, an anterior ethmoidal cell which

has grown sufficiently far into the frontal region to be topographically a frontal sinus.

The first evidence of the frontal sinus must not be sought in the frontal bone, but in the recessus frontalis of the middle nasal meatus. Lack of observance of this embryologic truth has led to such statements as: "in the newborn infant no trace of a frontal sinus is visible;" "the earliest sign of a frontal sinus is seen about the end of the first year in the form of a shallow depression;" "the frontal sinus is completely absent in the newborn infant." Poirier states that the frontal sinus is first seen about the end of the second year. Tillaux puts it as late as the twelfth year. Onodi, Davis, Schaeffer and others recognize the frontal sinus as such in some instances early in extrauterine life. Killian operated upon a diseased frontal sinus in a child 15 months old. As stated before, the recessus frontalis of the middle nasal meatus is demonstrable as early as the fourth fetal month and late in fetal life it becomes complex by the formation of the frontal furrows or pits, etc. One is not justified as a rule in the term child to hazard an opinion as to the specific point from which the sinus frontalis will ultimately develop. There are exceptions to this rule: occasionally at birth the genetic point for the sinus frontalis is obvious; again, one cannot be certain until the second or third year. The various potential rudiments (frontal recess and certain anterior ethmoidal cells, etc.) of the sinus are, however, far advanced by the end of fetal life. One must always bear in mind that the sinus frontalis is genetically and topographically ethmoidal before it is frontal and in this sense is conspicuously present at birth in all cases.

From the suprabullar furrow develop most of those anterior ethmoidal cells which in time honeycomb the bulla ethmoidalis (Figs. 156, 157 and 158). Rarely the suprabullar furrow seems to be the genetic point for the sinus frontalis. This may be apparent only and not the actual condition, since the most dorsal and cephalic of the frontal pits and the suprabullar furrow are at times continuous channels. This may lead to the interpretation that the frontal sinus developed from the suprabullar furrow, when in reality it developed from a frontal pit (early anterior ethmoidal cell).

The infundibulum ethmoidale at its ventral extremity usually ends blindly by forming one or more anterior ethmoidal cells (infundibular cells) of variable size and location. In the majority of cases such cells are lateral to the frontal recess. They may, however, grow far from the point of genesis and form conchal and agger cells (see page 221). Indeed, they may grow sufficiently far into the frontal region to become frontal sinuses. In any event they communicate always with the infundibulum

ethmoidale. The infundibulum ethmoidale and one or other of the frontal furrows or pits are frequently in the same axis in the fetus and at times are contiguous. Early resorption of the intervening barrier would cause a frontal furrow and the infundibulum ethmoidale to become continuous channels, and in the late fetus and infant, as well as in the adult, it would be difficult to prove that the channels were primitively discontinuous. It would be equally difficult to state the genetic point of the frontal sinus, *e.g.*, whether in the infundibulum ethmoidale or in a frontal cell. It must, however, here be pointed out that it is unusual initially for the infundibulum ethmoidale to be directly continuous with a frontal furrow or pit (Fig. 127). Of course, one must observe the embryonic and fetal nose at the proper ages to see the justice of this statement. Continuity of channels is, however, an occasional occurrence. Furthermore, the adult nasofrontal duct and the infundibulum ethmoidale are, strictly speaking, in the majority of cases, discontinuous channels. The latter is significant when one recalls the careless statement, frequently made without qualification, that, in the adult, the "infundibulum ethmoidale is continued upward as the nasofrontal duct into the sinus frontalis."

It will doubtless aid in making the adult conditions one meets more comprehensible if here reference is made to specific fetal conditions. In Fig. 110 the infundibulum ethmoidale is in line with the third frontal furrow, but not directly continuous with it. If in this case the frontal sinus should develop from the anterior ethmoidal cell of the first or second frontal furrows or from the frontal recess directly, the nasofrontal duct of the adult sinus would doubtless communicate directly with the middle nasal meatus and not with the infundibulum ethmoidale. If, on the other hand, the frontal sinus should develop from the cell of the third frontal furrow, the nasofrontal duct would be continued down to the infundibulum ethmoidale, but not be directly continuous with it, unless the bridge of intervening tissue were absorbed, as occasionally happens. A frontal sinus developing from the cell of the third frontal furrow would in all probability have a tortuous nasofrontal duct. This would, of course, depend largely upon the disposition and size of the other anterior ethmoidal cells.

In the dissection shown in Fig. 35 the infundibulum ethmoidale and the first frontal furrow are practically continuous with each other. Should the frontal sinus develop from the first frontal furrow in such a condition, the nasofrontal duct would be directly continuous with the infundibulum ethmoidale in the adult. One must not err, however, in such a condition by believing that the sinus frontalis necessarily developed

from the infundibulum ethmoidale. From adult relations it would appear as if the latter interpretation were correct; embryology, however, shows the error of this contention. If in the specimen shown in Fig. 35 the frontal sinus formation should take place from the cell of the second frontal furrow, the nasofrontal duct would be continued down to the infundibulum ethmoidale at an angle, but not be directly continuous with it. In the specimen shown in Fig. 111 (from a child aged 14 months) the whole frontal recess is extending and developing into the frontal sinus. In the latter case the adult sinus would in all probability have no true nasofrontal duct, but the sinus would open directly into the ventral and superior portion of the middle nasal meatus.

In a general way one may say that, when the frontal sinus develops from an anterior ethmoidal cell, the adult cavity will more frequently have a nasofrontal duct—the tortuosity of the duct depending upon the cell from which the sinus developed and upon the degree of development and disposition of the neighboring anterior ethmoidal cells. On the other hand, when the frontal sinus develops by a direct extension of the frontal recess there will in all likelihood be no true nasofrontal duct.

The Childhood Stage

The sinus frontalis as such may or may not be demonstrable at birth. The various potential rudiments of the sinus are far advanced; none, how-

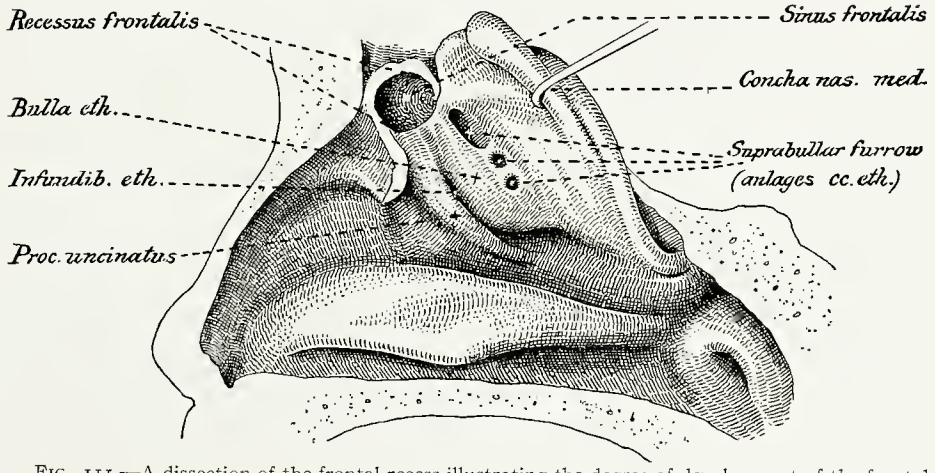

Fig. 111.—A dissection of the frontal recess illustrating the degree of development of the frontal sinus in a child aged 14 months. Note that the whole frontal recess is expanding into the frontal sinus. × 0.8.

ever, topographically frontal. As a rule, one cannot be certain of the actual frontal sinus until the sixth to the twelfth month of postfetal life. Notwithstanding, in some newborn babies the frontal sinus is more pre-

cocious than in the average and can be determined with reasonable certainty at this time.

The various outpouchings from the recessus frontalis continue to extend their boundaries and the one destined to form the frontal sinus (if the frontal recess is the source) ultimately comes in contact with the horizontal portion (pars orbitalis) of the frontal bone, and up to this time the mucous-membrane sac has a thin, compact bone matrix. Extension into the horizontal portion of the frontal bone now follows, thence between

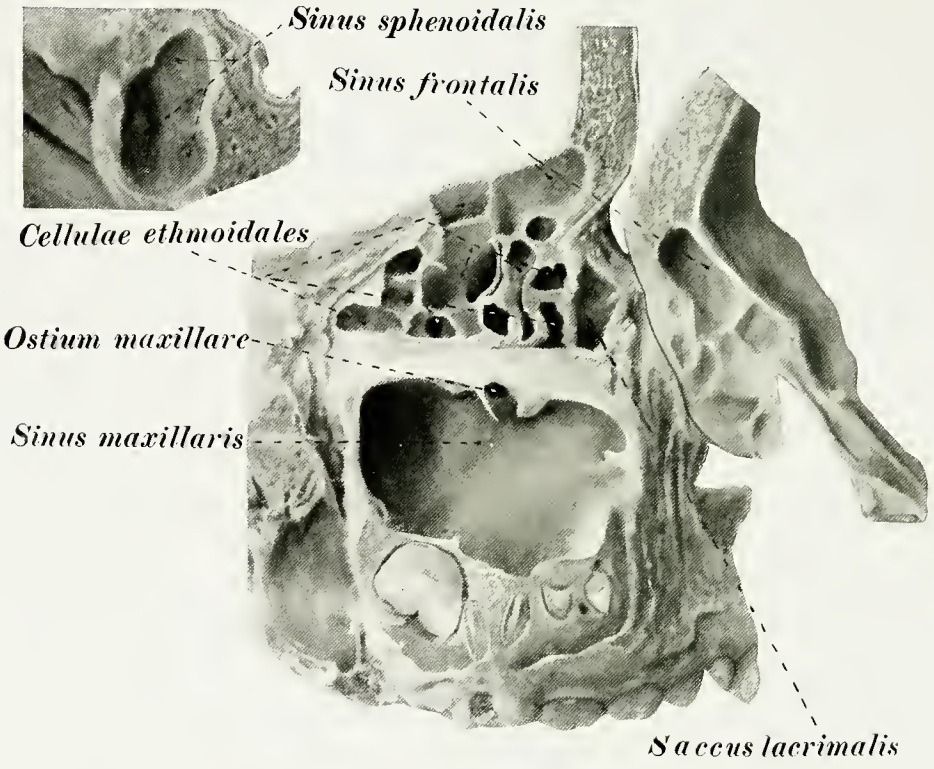

FIG. 112.—Photograph of a dissection of the paranasal sinuses of a child aged 6 years, 6 months and 15 days. (Dissection by Dr. Warren B. Davis.)

the tables of the vertical portion (squamous frontalis), by the simultaneous growth of the sinus and resorption of the cancellous bone. There is a great variation in growth. However, by the eighteenth or twentieth month the frontal sinus has "eroded" into and begun to ascend the vertical portion of the frontal bone, and by the middle of the third year the cupola of the sinus is above the level of the nasion. It should be here noted that in many instances the frontal sinus never invades far into the vertical portion, but grows extensively into the horizontal portion of the frontal

bone, forming a large air space (or spaces) over the orbit. This leads to the erroneous belief that there is frequently an agenesis of the frontal sinus.

When the sinus first invades the vertical portion of the frontal bone, it is nearer the inner than the outer plate. This leads to a thin dorsal wall—almost wholly compact bone—as opposed to a fairly thick ventral wall composed of both compact and cancellous (diplöe) bone. From the outset, in the invasion of the frontal bone, the frontal sinuses vary in size and shape and are usually asymmetrical. The septum frontale is seldom in the mid-sagittal plane, save at its base, ventrally. It is, however, well known that a persistent metopic suture usually precludes the likelihood of development of the sinus beyond the median plane (Fig. 66).

Table F gives the measurements in millimeters of the frontal sinus in a series of specimens from 6 months to 20 years of age. There is a gradual increase in the size of the sinus in one diameter or another as age advances. In a general way, this is true of all measurements. However, in some instances a certain diameter may lag far behind. Witness, for example, the short cephalocaudal diameter and the deep ventrodorsal diameter in the 17- to 18-year specimen—a sinus of the supraorbital type. This must, of course, not be taken as indicative of the type of sinus at

TABLE F

Age	Side	Distance of ostium frontale below nasion	Distance of cupola of sinus frontalis above nasion	Measurements			Size of ostium frontale
				Cephalocaudal (height)	Mediolateral (width)	Ventrodorsal (length)	
6–12 mos.	R	4.5	2.0 below	2.0	1.5	3.5	2.5×0.7
	L	4.5	1.5 below	2.0	2.0	3.5	2.5×0.4
1–2 yrs.	R	3.0	2.0	5.0	2.4	4.0	2.5×0.7
	L	3.5	1.6	4.9	2.6	5.0	2.6×0.8
3–4 yrs.	R	3.5	2.0	5.0	3.5	4.5	2.8×0.8
	L	4.0	2.5	7.0	4.0	5.5	2.8×0.8
5–6 yrs.	R	5.5	3.5	8.0	3.5	6.0	2.0×0.7
	L	4.0	3.0	7.0	3.5	6.0	2.8×0.8
7–8 yrs.	R	4.0	9.5	13.0	10.0	8.5	2.5×0.2
	L	4.0	10.0	15.0	10.0	7.0	2.7×2.1
10–11 yrs.	R	4.0	12.0	16.0	8.0	8.0	3.0×2.0
	L	6.5	12.0	17.0	9.0	5.5	3.0×2.5
13–14 yrs.	R	3.0	7.5	10.5	8.5	10.0	4.0×2.0
	L	4.0	11.0	15.0	9.0	12.5	3.5×2.0
14–15 yrs.	R	2.0	16.0	18.0	18.0	11.0	3.0×2.0
	L	3.0	15.5	18.5	20.0	11.0	3.0×2.0
17–18 yrs.	R	3.0	4.0	7.0	10.0	20.0	3.5×1.5
	L	6.0	11.0	16.0	18.0	16.0	4.0×2.0
19–20 yrs.	R	2.0	26.0	28.0	27.0	17.0	9.0×8.0
	L	2.0 above	28.0	26.0	26.0	16.0	3 0×2.0

this age, another specimen of the same age might show a totally different series of measurements.

The further development and variations in the anatomy of the sinus frontalis are best considered in connection with the adult stage.

The Adult Stage

General Considerations.—It is a well-established fact that the anatomy of the adult frontal sinus varies greatly—there being no constancy in size, shape or type. The sinuses in the same individual are usually asymmetrical and either or both may be present in duplicate or triplicate. The writer has, indeed, observed as many as four frontal sinuses on one side, each independent of another and with its own communication with the nasal cavity. Moreover, there is considerable variation in the manner of communication of the frontal sinus with the nasal cavity—a fact in accord with the varied embryology. Agenesis of the sinus has also been observed by a number of investigators. All of these variations are of utmost importance to the clinician, and an appreciation of them will doubtless aid in clearing up obscure cases.

The frontal sinus of the adult is seldom a simple chamber. It is frequently more or less divided into subcompartments or recesses by *incomplete* bony partitions. It lies between the two plates of the frontal bone in both the vertical (squamous frontalis) and horizontal (pars orbitalis) portions of the bone. Its ventral and thicker wall usually forms the prominence of the forehead above the eyebrows (the thickness varies from 1 to 10 mm.). *A prominent supraorbital swelling (superciliary ridge) must, however, not be taken to mean an undoubted large frontal sinus.* The prominence is very misleading at times if thought to be indicative of the size of the frontal sinus. The dorsal and cephalic wall separates the frontal sinus from the frontal lobe of the brain. When the frontal sinus is extensively developed over the orbit it is in relationship with the gyri frontales: inferior, medius, and superior. The caudal wall of the sinus is in relationship with the tissues of the orbit and in part overlies the anterior ethmoidal cells. Indeed, if the frontal sinus has developed far dorsad between the plates of the horizontal part of the frontal bone, it will overlie the posterior ethmoidal cells likewise. The frontal sinus occasionally extends into the crista galli. The septum frontale is always present; seldom, however, in the mid-sagittal plane throughout, and according to the author's specimens is *very rarely* perforated, save in disease. It is, however, often of a papery thickness in certain parts.

Size of the Adult Frontal Sinus.—Brühl in a study of the frontal sinus found the capacity of the combined sinuses to vary from 6 to 16 cc. The writer's investigations show the combined volume of the right and left frontal sinuses to vary from 1 cc. to 45 cc. The extremes in capacity represent, of course, relatively few specimens and should not be taken into account in speaking of the average measurements. The following table (G) taken from the studies of three writers gives the average size in millimeters of the sinus frontalis in the different planes:

TABLE G

Author	Cephalocaudal (height)	Mediolateral (width)	Ventrodorsal (length)
Boege	20.8	23.6	16.1
Loeb	34.0	23.0	21.0
Schaeffer	27.9	23.25	19.25

A series of specimens taken at random from a larger series investigated by the writer show variations in the several diameters as follows (table H):

TABLE H

No.	Cephalocaudal (height)		Mediolateral (width)		Ventrodorsal (length)	
	R	L	R	L	R	L
1	26	30	31	24	45	44
2	18	18	24	29	19	33
3	8	12	13	22	6	10
4	29	22	27	32	40	42
5	10	9	5	19	5	7
6	26	30	16	21	35	40
7	16	20	20	35	27	36
8	17	17	24	30	20	37

Extensive Pneumatizations by the Frontal Sinus.—The writer recently encountered frontal sinuses of enormous size, far exceeding Brühl's maximum. Witness, for example, the dissection of an adult male shown in Fig. 113. The skull has three frontal sinuses, one on the right side and two on the left, in communication with the frontal recess of the related side. The whole of the orbital (horizontal) portion of the frontal bone is pneumatized. Indeed, the frontal sinuses are not confined to the frontal bone: Laterally and dorsally they extend into the great or temporal wings (alæ magnæ) and dorsally and medially into the small or orbital wings (alæ parvæ) of the sphenoid bone. The medial one of the two left sinuses

extends into the crista galli of the ethmoid bone. Moreover, the sinuses extend into the frontal or nasal processes of the maxillæ and into the nasal bones. Numerous finger-like projections of the sinuses have hollowed out the frontal (vertical) portion of the frontal bone to an unusual degree. The total capacity of the three frontal sinuses represented in Fig. 113 is 38 cc. Everywhere the walls of the sinuses are extremely thin. The

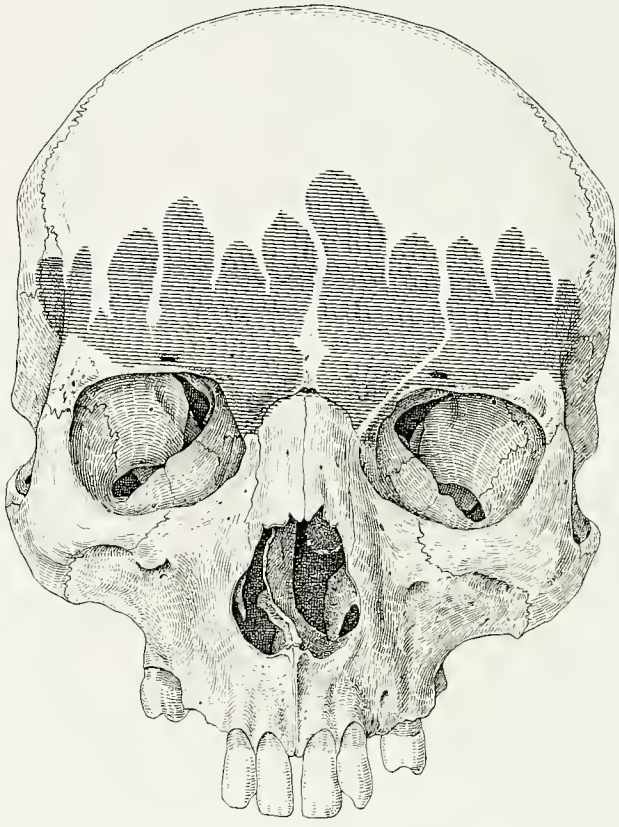

FIG. 113.—Skull from an adult male. The frontal sinuses in the vertical portion of the frontal bone, in the great wings of the sphenoid, and in the temporal bones are represented by cross-hatching. Note that there are two sinuses on the left side and one on the right. The orbital extension of the sinuses is, of course, not shown. The combined capacity of these unusually large frontal sinuses was thirty-eight cubic centimeters. (*After J. P. S., Annals of Surgery*, December, 1916.)

enormous capacity of the sinuses in this specimen can better be appreciated when one recalls Brühl's findings (page 147). Clinically it is of importance to appreciate the additional anatomic relationships of the frontal sinuses in such extensive pneumatizations.

Even more extensive are the frontal sinuses illustrated in Figs. 114 and 115. The dissections are from an adult male. Every part of the orbital (horizontal) portion of the frontal bone is hollowed out. The

intracranial walls of the frontal sinuses are crowded bullous-like toward the anterior cranial fossa. Extensive and numerous finger-like recesses of the sinuses project variously into the vertical portion of the frontal bone (Fig. 115). On both sides the sinuses extend into the great or temporal wings (alæ magnæ) and into the lesser wings (alæ parvæ) of the sphenoid

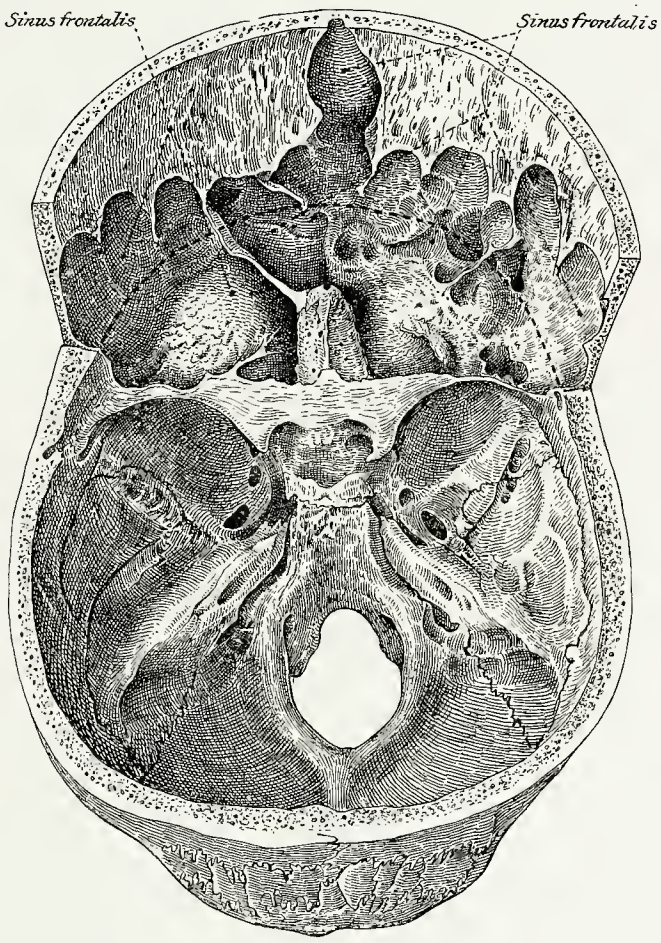

FIG. 114.—A dissection of enormously developed frontal sinuses. The intracranial walls of the sinuses have been removed (see text, page 147).

bone. There is even an extension bilaterally into the temporal bones and well down to the root of the nose into the nasal bones and into the frontal or nasal processes of the maxillæ. In Fig. 114 the intracranial wall of the sinus is removed, thus exposing the sinuses in their entirety. It is especially important to note the extensive anatomic relationships of the frontal sinuses in this specimen. The two sinuses are markedly asym-

metrical. Many recesses and incomplete bony septa are present. The capacity of the two sinuses (Figs. 114 and 115) is 45 cc.

In a study of the heads of hundreds of cadavers the author frequently encountered very large frontal sinuses, but such extensive pneumatization of the frontal and related bones by the frontal sinuses as found in these two cadavers (Figs. 113 and 115) is unique in his experience and in all probability in the literature on the subject.

Supernumerary Frontal Sinuses.—Unilateral and bilateral supernumerary frontal sinuses are extremely common. They occur in both the

FIG. 115.—An adult skull showing extensive pneumatization by the frontal sinuses of the vertical portion of the frontal bone. In Fig. 114 is illustrated the supraorbital extent of the frontal sinuses in the same skull (see text, page 147). (*After J. P. S., Annals of Surgery*, December, 1916.)

vertical and horizontal portions of the frontal bone. Multiple frontal sinuses are placed either side by side in the coronal plane or one dorsal to the other in the sagittal plane. Intermediate relations are encountered. The writer has observed as many as six frontal sinuses in one skull, four on one side and two on the other. Cryer observed as many as five in one skull. Regardless of the number, each sinus is normally independent of another and has its own ostium of communication with the frontal region of the middle nasal meatus.

Cryer[1] in commenting on a specimen with four frontal sinuses placed side by side in the coronal plane aptly says: "Some writers would class the two middle sinuses as anterior ethmoidal cells which had invaded the frontal bone. If these cells should exist without the two large sinuses, they would then be called frontal sinuses by these same writers." In a certain sense the frontal sinuses are always anterior ethmoidal cells which have invaded the frontal bone. However, one cannot get away from the topography of these supernumerary sinuses and their classification as frontal rather than ethmoidal paranasal chambers is eminently proper. Genetically, there is abundant reason for multiple frontal sinuses (see page 140).

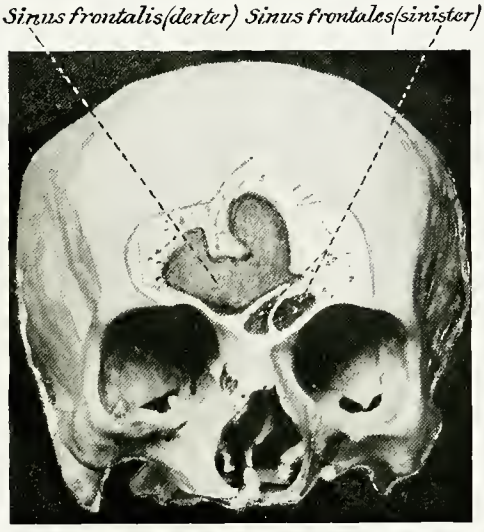

FIG. 116.—The frontal sinuses of an adult. Note the marked asymmetry.

In Figs. 125 and 126 are represented dissections of adult naso-frontal regions in which two frontal pits (early anterior ethmoidal cells) developed sufficiently far to be topographically frontal sinuses. In Fig. 126 the first and second frontal pits developed into frontal sinuses; in Fig. 125, the second and third. In both instances the sinuses communicate independently with the recessus frontalis of the middle nasal meatus. At times when the frontal sinus exists in duplicate (or triplicate) one sinus may encroach bullous-like on the other. The name *bulla frontalis* is, however, applied to infundibular and other cells which encroach upon the dorsocaudal boundary of the frontal sinus (Figs. 117 and 118).

A common type of duplicate frontal sinus is illustrated on the left

[1] Loc. cit.

side of the skull shown in Fig. 120. In this skull the single right sinus has pneumatized both the horizontal and vertical portions of the frontal bone. On the left side the frontal sinus is present in duplicate. The left ventral sinus has invaded both the horizontal and vertical portions of the frontal bone and immediately dorsal to it is another, absolutely independent frontal sinus which has pneumatized the remainder of the horizontal part of the frontal bone as well as portions of the greater and lesser wings of the sphenoid bone. This type of sinus is often overlooked in operative procedures, owing to its depth from the frontal region, its position and relations. In order to expose it from the frontal region, the removal of two plates of bone would be necessary.

The Frontal Bulla (bulla frontalis).—Not infrequently one or other of the anterior ethmoidal cells encroaches upon the floor of the frontal

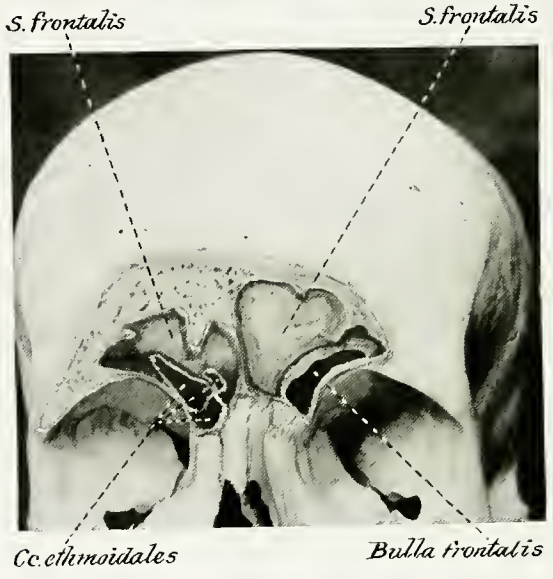

FIG. 117.—The frontal sinuses and encroaching ethmoidal cells of an adult skull.

sinus, pushing the latter balloon-like into the lumen of the sinus. To these frontal extensions of ethmoidal cells is applied the term frontal bullæ. There is no constancy, however, as to which of the ethmoidal cells impinges or encroaches upon the confines of the frontal sinus in the formation of a so-called frontal bulla. It may be an extensively developed cell of the bulla ethmoidalis (bullar cell), of the infundibulum ethmoidale (infundibular cell), or of the recessus frontalis (frontal cell). The frontal bulla is, therefore, merely an extension of an ethmoidal cell at the expense of the lumen of the frontal sinus with, however, no connection whatever

with the sinus. At times anterior ethmoidal cells arrange themselves tier-like in the floor of the frontal sinus (Fig. 118). Not infrequently they encroach markedly upon the nasofrontal duct and cause it to assume a sinuous course. The frontal bulla may be so prominent (essentially a frontal sinus) and so located that in the usual Killian operation upon the frontal sinus it would be the frontal bulla and not the frontal sinus that would be opened (Fig. 118).

FIG. 118.—A dissection showing anterior ethmoidal cells arranged tier-like in the floor of the right frontal sinus.

Sf = sinus frontalis; *Bf* = bulla frontalis; *Ce* = cellula ethmoidalis.

The belief that the balloon-like structure in the floor of the frontal sinus is always an ethmoidal cell accompanied by a frontal sinus of the same side is not based upon facts. Witness, for example, Fig. 85, in which is represented a dissection of the frontal sinuses showing marked asymmetry. It will be noted that the right frontal sinus in both instances projects to a marked degree to the left of the mid-sagittal plane. The only evidence of a right frontal sinus is the elongated balloon-like swelling in the floor of the left extension of the right frontal sinus. Obvi-

ously had the left side alone been dissected the natural inference would have been that the swelling over the orbit was a bulla frontalis and that the frontal sinus over it was an asymmetrical left frontal sinus. Strangely, however, the "bulla frontalis" happens to be the left frontal sinus and the right frontal sinus occupies the greater portion of the fields usually occupied by the conjoint right and left sinuses. Such specimens are of not infrequent occurrence and argue against the statement that frontal bullæ are *always* cranial extensions of anterior ethmoidal cells into the lumen of the frontal sinus of the same side.

Frontal Sinus Diverticula.—Rarely frontal sinuses depart markedly from the average and early give off buds which develop into diverticula[1]

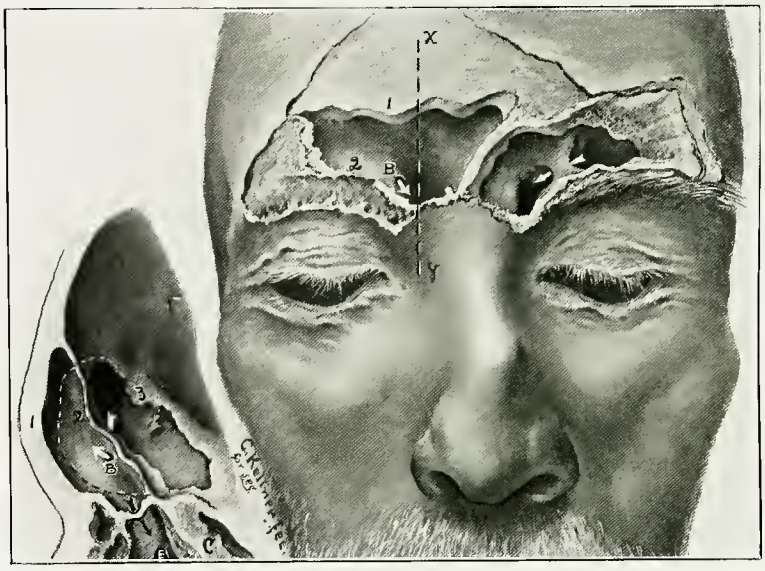

FIG. 119.—A dissection of the frontal sinuses of an adult. On the right side is a goodly sized frontal sinus, in a sense a diverticulum, immediately dorsal to the usual frontal sinus. Yale University Anatomical Series. (See text, page 154.)

that communicate with the parent sinus in the adult. The dissection of a male head shown in Fig. 119 is apropos. The ventral view of the right sinus is more or less typical. The sinus projects beyond the mid-sagittal plane to the left, a very common variation. Its greatest transverse measurement is 50 mm. and the greatest ventrodorsal measurement is but 10 mm. It does not extend to any appreciable degree over the orbit, but projects far into the squama frontalis. In these respects it contrasts strongly with the left frontal sinus.

On the dorsal wall of the right frontal sinus, as shown in the ventral

[1] J. Parsons Schaeffer, Annals of Surgery, Sept., 1912.

view in the larger figure, immediately lateral to the line *X-Y*, at point *B*, is noted a round ostium, about 2 mm. in diameter. This ostium led to the finding of the large diverticulum immediately dorsal to the usual and normal sinus. Careful dissection demonstrated the diverticulum as communicating with the right frontal sinus proper only, through the small aperture *B*, shown in both figures. In the small figure to the left, a sagittal section through the right frontal sinus is revealed, the large diverticulum from the sinus proper, dorsal in position. A reference to the figure will show the outline of the diverticulum, passing well over the orbit, beneath and dorsal to the right frontal sinus proper. It will be noticed that three plates of bone intervene between the soft tissues of the forehead and the dura mater: first, the plate (1) ventral to the right frontal sinus proper; second, the plate (2) dorsal to the sinus proper and ventral to the diverticulum; third, the plate (3) dorsal to the diverticulum and forming the ventral boundary of the anterior cranial fossa (*F* in the figure designates the anterior cranial fossa).

The diverticulum measures 37 mm. in its greatest transverse dimension and 30 mm. in its greatest ventrodorsal extent. It projects somewhat into the squama frontalis, and extends well dorsad into the pars orbitalis of the frontal bone.

The frontal sinus proper of the right side communicates with the frontal recess of the middle nasal meatus indicated by the black arrow (the middle nasal concha, *C*, is partly cut away so as to expose the frontal recess). The ethmoidal infundibulum (*E*) ends blindly in an anterior ethmoidal cell. The large diverticulum communicates with the right frontal sinus proper through the ostium marked *B* as indicated by the white arrows in both figures.

Had the right frontal sinus proper, as shown in the large figure, been opened surgically in the living subject, the large diverticulum, dorsal in position, would in all likelihood have been entirely overlooked. The natural inference, of course, would have been that the bony plate marked "2" was the plate separating the frontal sinus from the dura mater and brain. A reference to the sketch in the sagittal plane demonstrates the fallacy of such a conclusion.

In concluding this note a word as to the probable genesis of this large diverticulum may not be amiss. There is all evidence in the specimen that the right frontal sinus proper had its genesis in an anterior ethmoidal cell, which in turn had its genesis in one of the frontal furrows on the lateral wall of the frontal recess of the fetus. The ethmoidal cell continued its development sufficiently far to become topographically the right frontal

sinus. The natural inference is, since all of the paranasal chambers are primarily outgrowths from preformed nasal spaces, that sometime during the development of the right frontal sinus a dorsal evagination from the frontal sinus grew into the plate of bone which separated the right frontal sinus from the dura mater. The evaginated sac continued to grow and the bone immediately surrounding the sac was resorbed; the two processes,

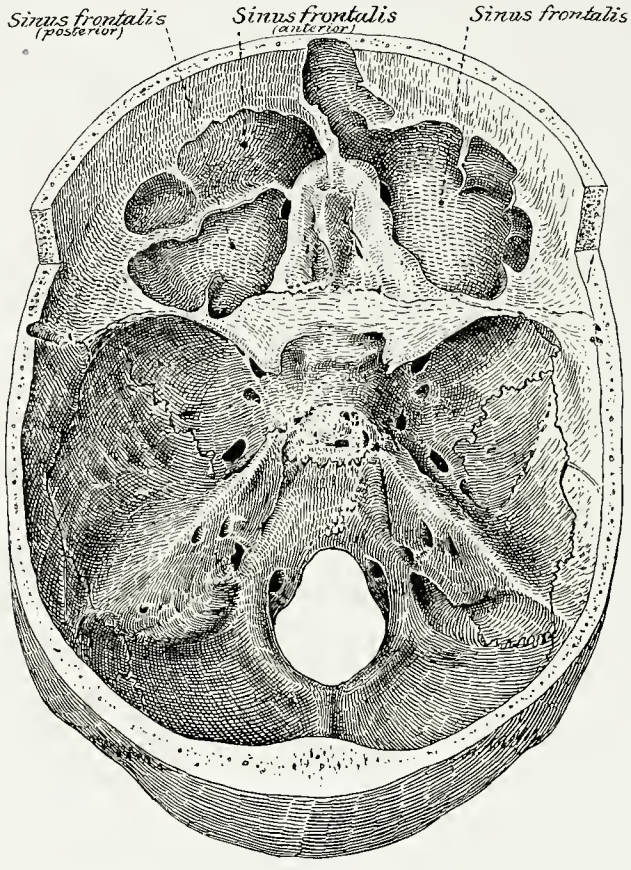

FIG. 120.—A specimen in which there is a duplication of the frontal sinus on the left side. The anterior of the two sinuses is largely confined to the vertical portion of the frontal bone and the posterior to the horizontal portion. In the usual Killian operation on the frontal sinus the posterior of the two left sinuses would in all likelihood be overlooked. The posterior sinus might be diseased and the anterior one opened with negative findings. (*After J. P. S.*)

growth of the sac and resorption of bone, taking place *para passu* with the further growth of the sinus proper. In this manner the large diverticulum or accessory frontal sinus was formed dorsal to the frontal sinus proper. The plate of bone marked *B*, although very thin, not being entirely resorbed, remained as a partition, completely separating the two cavities, save at the point of the original budding of the diverticulum; the point of

origin of the sac remaining, of course, as the ostium of communication between the two cavities in the adult.

Agenesis of the Frontal Sinus.—Unilateral and bilateral absence of the frontal sinus has been reported. Boege claims to have found bilateral absence in 4 per cent. of 203 skulls examined. The writer questions the frequency of agenesis in Boege's results, because in a large series of specimens (well over 300) the nearest approach to an absent

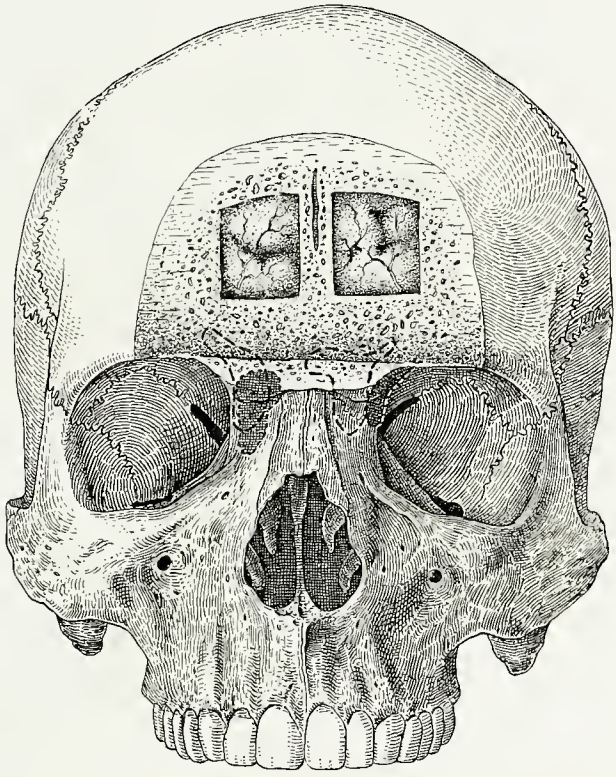

FIG. 121.—An adult skull in which it was believed that the frontal sinuses were wholly wanting. A large frontal wedge of bone exposed the cerebral hemispheres, yet failed to expose frontal sinuses. Further dissection showed the frontal sinuses present in duplicate on both the right and left sides in the horizontal portion of the frontal bone, hugging the ethmoidal labyrinth and extending well over the orbit. The frontal sinuses are indicated by cross-hatching and by dotted lines.

frontal sinus is shown in Figs. 129 and 123. In Fig. 129 a cavity in communication with the frontal recess extends above the nasion which in reality is a frontal sinus. However, it is totally absent in the vertical portion of the frontal bone and doubtless would be considered a case of absent frontal sinus by many investigators. In the specimen represented in Fig. 123 both frontal sinuses are seemingly wholly wanting. However, this is true only of the vertical portion of the frontal bone. The

small openings expose goodly sized frontal sinuses in the horizontal or orbital portion of the bone, hugging closely the ethmoid labyrinth throughout and extending medially along the orbit. Frontal sinuses in this position would be wholly missed by the usual frontal approach surgically and in all likelihood would be classed as wanting. Frequently sinuses in this position are, of course, ethmofrontal rather than purely frontal. However, in this particular instance the sinuses are wholly within the confines of the frontal bone.

Meyer reports bilateral absence of the frontal sinus in a white male, aged 52 years. His case likewise showed a frontal recess which enlarged in a slightly dilated extremity about 3 mm. superior to the nasofrontal suture.

FIG. 122.—An adult skull with extremely small frontal sinuses.

Errors have doubtless been made in assuming the frontal sinus absent in those cases in which there was no pneumatization of the frontal or vertical portion of the frontal bone (squama frontalis). It is well to recall that the frontal sinus is genetically an outgrowth from the middle nasal meatus and that the first evidence of the sinus must not be sought in the vertical portion of the frontal bone. Indeed, in some instances the frontal sinus never does invade the vertical portion of the frontal bone, development taking place wholly in the horizontal or orbital portion.

Witness, for example, the skull represented in Fig. 121. This specimen was exhibited as a skull with absent frontal sinuses. The vertical saw-cut exposed both frontal lobes of the brain and met at right angles

a deep horizontal cut made at the level of the nasion (point of contact of the frontal bone with both nasals). Even with this large wedge of bone removed, no frontal sinus was exposed, and in a sense the exhibitor of the skull was justified in declaring the frontal sinuses absent. Through the kindness of Doctor Hoffman the writer was given an opportunity to examine the skull. The orbital type of frontal sinus was at once suspected. Small trephine openings made at the highest point of the nasal processes of the maxillæ revealed two fairly large frontal sinuses hugging closely the

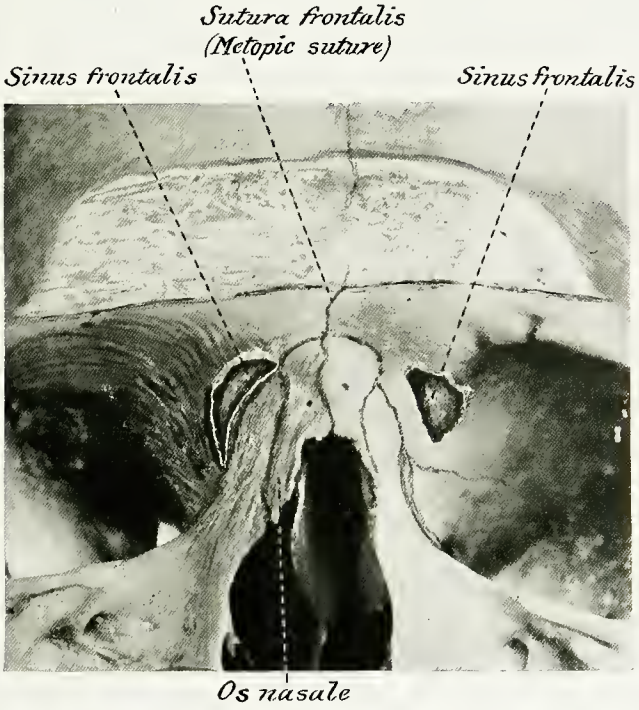

FIG. 123.—An adult skull with a persistent frontal or metopic suture. Note that the frontal sinuses are completely wanting in the vertical or frontal portion of the frontal bone, but present in the horizontal or orbital portion. The vertical saw cut in the frontal plane failed to reveal frontal sinuses, and it was believed that there was total agenesis of these paranasal chambers. Further search, however, resulted in finding frontal sinuses as depicted in the illustration.

ethmoidal labyrinth and extending for some distance into the horizontal portion of the frontal bone over the medial and cephalic wall of the orbit. On the left side a supernumerary sinus was found immediately dorsal to the one ventrally placed. Moreover, a supernumerary frontal sinus was found on the right side medial to the frontal sinus first exposed and lateral in position. In the drawing the outlines of the four frontal sinuses are given. They are wholly dorsal to the vertical saw-cut. The ordinary procedure for exposing the frontal sinuses would, of course, have failed

to reveal the chambers in this case. Four frontal sinuses, therefore, existed where a total absence was thought to be the condition.

Very careful examination is necessary before one is justified in declaring a total agenesis of the frontal sinus.[1] It is very rare. Of course, some would call such sinuses ethmofrontal. At times the frontal sinus remains extremely diminutive in size. It is very common to err in these cases and declare the frontal sinuses absent. Only *careful* search and a realization of the great variations in the anatomy keep one from "going wrong."

The Nasofrontal Connections in the Adult.—As stated in the introduction, in order to properly interpret points in the adult anatomy of a

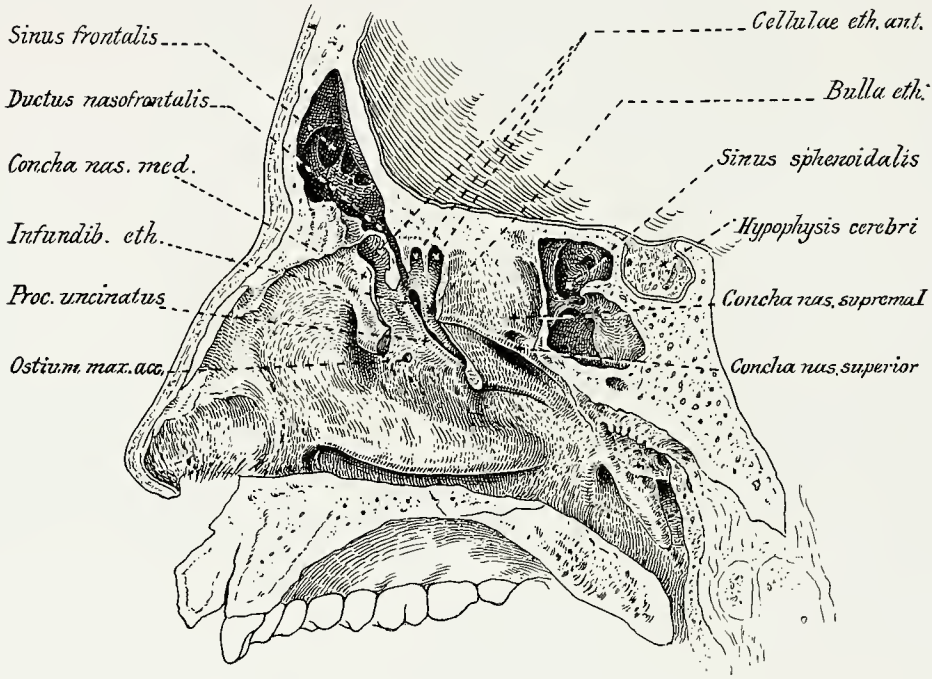

FIG. 124.—Dissection of an adult lateral nasal wall with especial reference to the frontal recess and the nasofrontal connections. Note that the nasofrontal duct and the infundibulum ethmoidale are discontinuous channels. (See text, pages 161–164.)

region, it is frequently necessary to revert to the embryology of the part or parts concerned. This, indeed, is true of the nasofrontal region.[2] Doubtless many of the erroneous statements extant in the literature on the connections of the frontal sinus with the nasal fossa are the result

[1] J. Parsons Schaeffer: Further Observations on the Anatomy of the Sinus Frontalis in Man, Annals of Surgery, December, 1916.

[2] J. Parsons Schæffer: The Genesis, Development, and Adult Anatomy of the Nasofrontal Region in Man, Amer. Jour. Anatomy, Vol. 20, July, 1916.

of drawing conclusions from a study of too few specimens, of studying adult material alone, and of errors in interpretation due to the fact that embryologic and adult studies were not carried on simultaneously.

The adult nasofrontal region presents a varied anatomy—a fact in accord with the varied genesis of the parts involved. In the adult, one usually finds evidence of the previous embryologic condition that must have obtained in the particular case. Careful analysis of the nasofrontal region reveals, as a rule, the derivatives of the frontal furrows or pits and

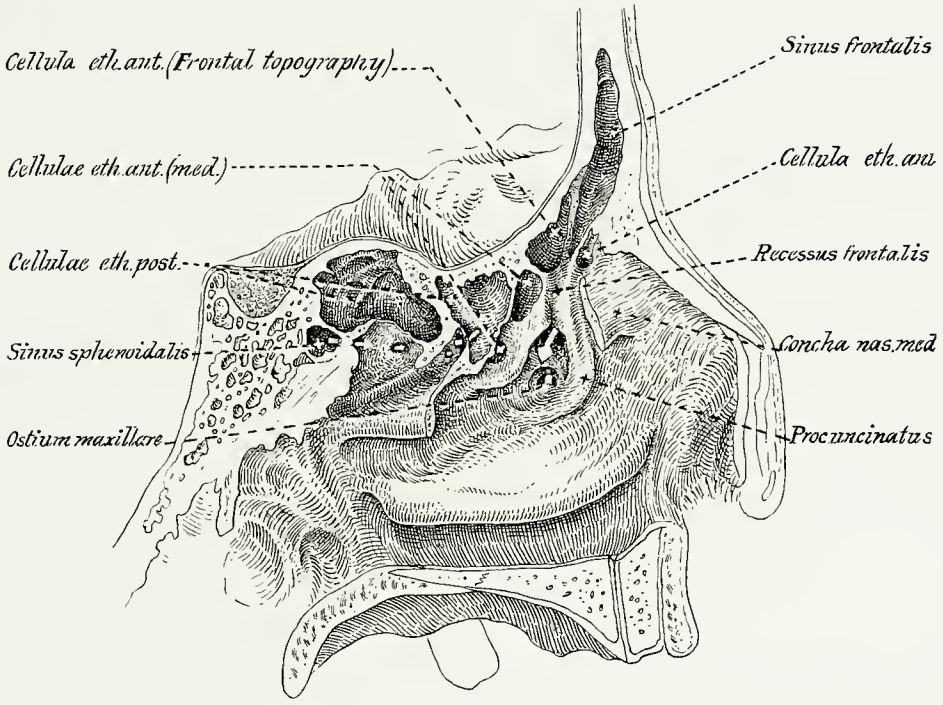

FIG. 125.—A dissection of the lateral nasal wall showing the ethmoidal cells open and one of the posterior ethmoidal cells projecting into the body of the sphenoid bone at the expense of the sphenoidal sinus. It will be noted that the latter is extremely small. The frontal recess receives the frontal sinus and certain anterior ethmoidal cells. The uncinate process is curved caudally and laterally, thereby exposing the maxillary ostium in the depth of the ethmoidal infundibulum. It is in such cases that probing of the maxillary ostium is possible.

of the frontal folds or conchæ; provided, of course, these structures were differentiated. As stated elsewhere, there are instances in which the lateral wall of the recessus frontalis does not become configured by pits and folds. Moreover, in some specimens the adult anatomy is so altered that interpretation is very difficult, even impossible.

It may be well here to refer to specific dissections of the region for study and analysis. In Fig. 124, for example, is represented an adult

nasofrontal region exposed for study by the removal of the operculating middle nasal concha. There is positive evidence of four embryological frontal furrows or pits. The first or most ventral of the latter differentiated into an anterior ethmoidal cell of small dimension, communicating directly with the middle nasal meatus medial to the processus uncinatus. The third and fourth frontal furrows or pits likewise developed into anterior ethmoidal cells, both of which communicate with the middle nasal meatus cephalic to the semilunar hiatus of the infundibulum eth-

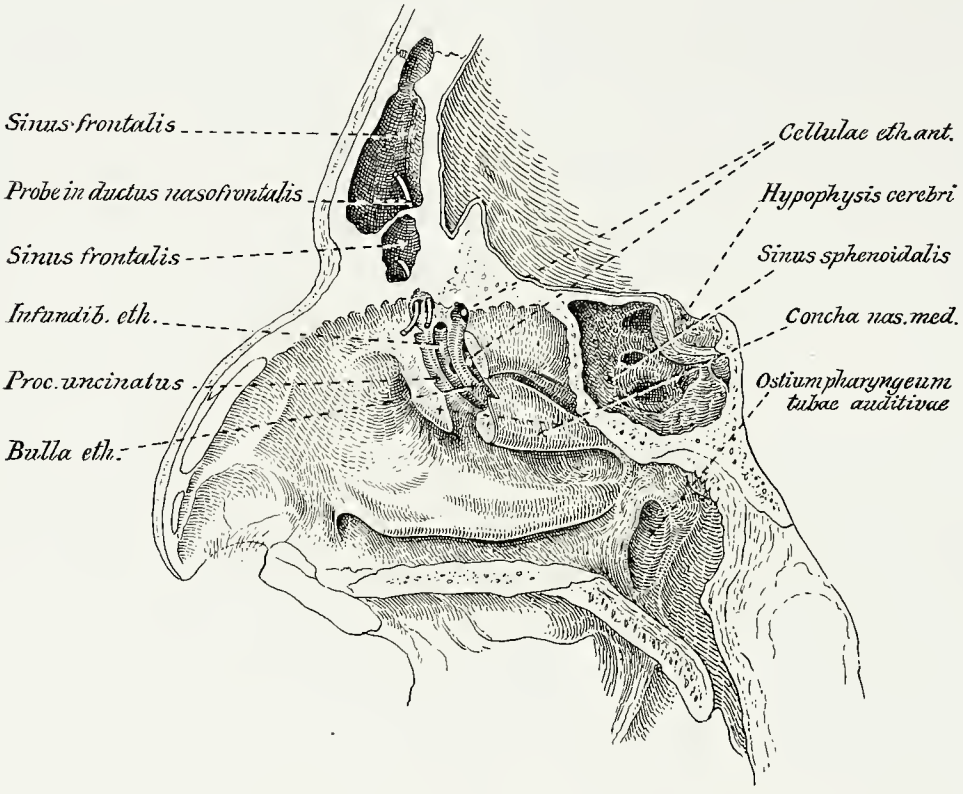

FIG. 126.—A dissection in which the infundibulum ethmoidale and the nasofrontal ducts are not only discontinuous channels, but channels in non-alignment. (Compare with Figs. 124 and 127.)

moidale. The second frontal furrow or pit after first developing into an anterior ethmoidal cell continued to extend its boundaries until it became topographically the frontal sinus. It should be noted that the duct of the frontal sinus (ductus nasofrontalis) is in the position of the embryonic second frontal furrow or pit and that it is in the same axis as the infundibulum ethmoidale and the hiatus semilunaris, but not in direct continuity with them. The sinus frontalis in this instance (Fig. 124) communicates, therefore, with the recessus frontalis directly via the ductus nasofrontalis.

Moreover, the infundibulum ethmoidale ends blindly as an anterior ethmoidal cell (infundibular cell) lateral to the recessus frontalis and the ductus nasofrontalis.

The anatomy represented in Fig. 124 is that found in a large number of adult specimens and is illustrative of one of the anatomic types of this region. It should be noted that the infundibulum ethmoidale is not directly continuous with the nasofrontal duct, but that it bears an intimate and important relation to it. The relation is, in a sense, a *con-*

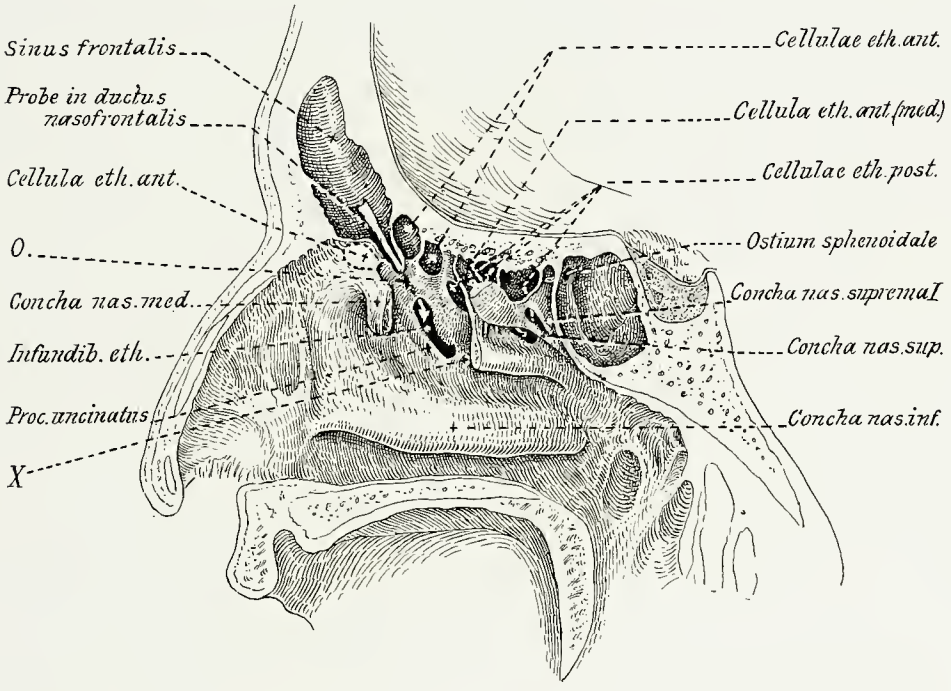

FIG. 127.—A dissection of an adult lateral nasal wall. Especially note that the infundibulum ethmoidale is in direct continuity with the frontal sinus—a bridge of mucous membrane (*O*) extending across the frontal end of the infundibulum ethmoidale; moreover, that the uncinate process at its dorsal termination causes the infundibulum ethmoidale to end in a deep pocket (*X*), just over the ostium of the maxillary sinus. The anatomy of this specimen is such that the maxillary sinus would perforce become a cess-pool for an infected frontal sinus. (Compare with Fig. 124.)

tiguous but not a continuous one. Drainage from the frontal sinus would find its way partly into the middle nasal meatus directly and partly into the infundibulum ethmoidale. An exploratory probe passed toward the frontal region via the infundibulum ethmoidale would, of course, find its way into the ventral, blind end of the latter and not into the frontal sinus. To probe the frontal sinus in this case it would be necessary to pass through the proximal ostium of the ductus nasofrontalis located in the recessus frontalis.

It is very interesting and instructive to compare the embryologic anatomy of the recessus frontalis illustrated in Fig. 110 with the adult anatomy illustrated in Fig. 124. In the former the third frontal furrow and the infundibulum ethmoidale are in the same axis; in the latter, the second frontal furrow (now the nasofrontal duct) is in the same axis as the infundibulum ethmoidale. If in Fig. 36 the sinus frontalis had developed from the same frontal furrow as in Fig 124, the relation between the ductus nasofrontalis and the infundibulum ethmoidale would have been less intimate.

The dissection of the adult nasofrontal region illustrated in Fig. 125 gives evidence of the early embryologic frontal furrows or pits. The adult derivatives of the latter are readily identified. The first frontal pit developed into a small anterior ethmoidal cell which is in direct communication with the recessus frontalis by means of its ostium. The second and the third frontal pits developed into the frontal sinuses (sinus frontalis in duplicate). Both of the latter communicate directly by means of independent ostia with the recessus frontalis, no ductus nasofrontales being present. A study of the dissection shown in Fig. 125 clearly points out that the infundibulum ethmoidale terminates blindly (indicated by a probe) as an anterior ethmoidal cell (infundibular cell) lateral to the recessus frontalis. Loose interpretation of the anatomy of the frontal region in this instance might lead to the erroneous statement that the frontal sinus developed as an extension of the infundibulum ethmoidale. One sees even a channel-like depression on the lateral wall of the recessus frontalis connecting in a sense the frontal sinus with the infundibulum ethmoidale. It is obvious that the drainage from the frontal sinus would in part find its way into the infundibulum ethmoidale, thence via the latter to the ostium maxillare and into the maxillary sinus (antrum of Highmore).

In Fig. 128 we have evidence of four embryologic frontal pits. The derivatives of these pits are two anterior ethmoidal cells and two frontal sinuses, all in communication with the recessus frontalis of the middle nasal meatus. The first (most ventral) and fourth (most dorsal) frontal pits developed into two small ethmoidal cells. The second frontal pit developed sufficiently to be topographically a frontal sinus (indicated in the drawing as an anterior ethmoidal cell). The frontal sinus proper took its origin from the anterior ethmoidal cell which had its genetic point in the third frontal pit. The result of the encroachment of the cell from the second frontal pit, is a narrow, tortuous nasofrontal duct communicating between the frontal sinus and the frontal recess. As in Figs. 124 and 125,

in Fig. 128 the infundibulum ethmoidale ends blindly lateral to the recessus frontalis.

Elsewhere mention is made of occasional adult specimens in which the ductus nasofrontalis and the infundibulum ethmoidale are *continuous* channels. In Fig. 127 is represented a dissection of an adult nasofrontal region in which the ventral extremity of the infundibulum ethmoidale is directly continuous with the ductus nasofrontalis and secondarily with the sinus frontalis. Moreover, the dissection shows a plate of tissue intervening between the free border of the processus uncinatus and the bulla ethmoidalis, thus bridging over the ventral extremity of the infundi-

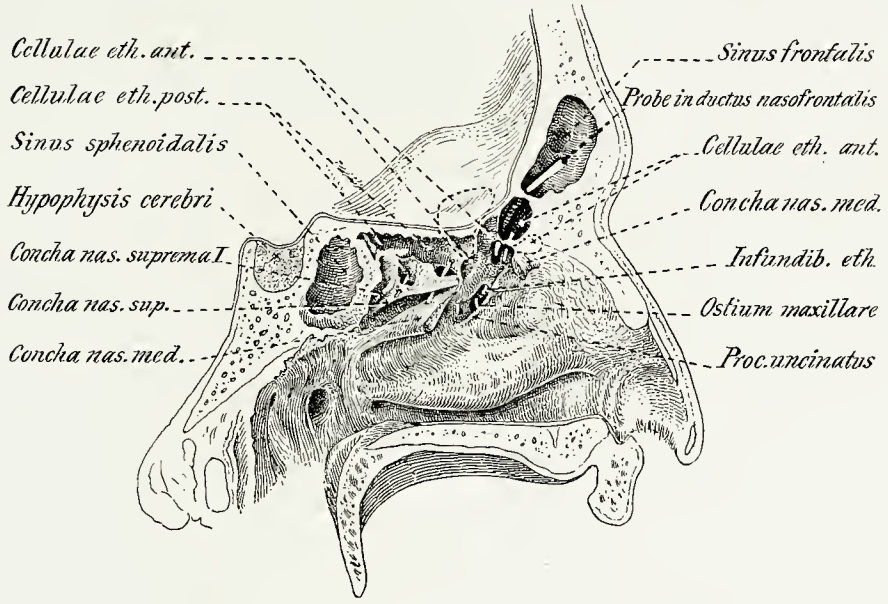

FIG. 128.—Dissection of an adult lateral nasal wall. Especially note the tortuous and narrow nasofrontal duct and its discontinuity with the ethmoidal infundibulum. Moreover, note the impingement of one of the anterior ethmoidal cells on the confines of the nasofrontal duct. Such nasofrontal connections are inefficient as drainage channels, and readily occluded by inflammatory conditions.

bulum ethmoidale and, in a sense, replacing the hiatus semilunaris in this position. One encounters difficulty in interpreting the anatomy of the nasofrontal connections in this specimen. Did the frontal sinus develop from the ethmoidal infundibulum (by a direct extension or from an infundibular cell) or from a second frontal pit (early anterior ethmoidal cell)?

The infundibulum by its ventral and cephalic extension usually comes into topographic relationship with some of the anterior ethmoidal cells which arise from the frontal pits. In this instance (Fig. 127) a

relationship may early have been established with the second frontal pit. Resorption of the intervening barrier would, of course, bring the ethmoidal infundibulum and its semilunar hiatus into direct continuity with the anterior ethmoidal cell arising from the second frontal pit, likewise with the frontal sinus. Moreover, the specimen gives positive evidence of three frontal pits (now cellulæ ethmoidales anterior). Whether an additional frontal pit, which gave rise to the frontal sinus, was present in the position of the adult nasofrontal duct is, of course, impossible to say. Two of the anterior ethmoidal cells are separated by a considerable interval. This space may have been the second frontal pit. Again, the two frontal pits in question (cellulæ ethmoidales anterior) may have been crowded apart by a bullous-like ventral and cephalic growth of the ethmoidal infundibulum in the establishment of the frontal sinus.

Drainage from the frontal sinus in such instances (Fig. 127) would pass almost wholly into the ethmoidal infundibulum and via the latter to the ostium maxillare, thence into the maxillary sinus. Should the floor of the ethmoidal infundibulum in such cases be largely replaced by an elongated ostium maxillare (a rather common occurrence, Fig. 103), the frontal sinus and the maxillary sinus would from a *practical viewpoint* be in direct communication. It should be recalled that the maxillary sinus is genetically an outgrowth from the floor or lateral wall of the infundibulum ethmoidale and that the initial area of the outgrowth varies considerably in extent, thus accounting for the varied size of the adult ostium maxillare.

The Nasofrontal Duct (ductus nasofrontalis, infundibulum of the frontal sinus).—The duct leading from the frontal sinus to the nasal fossa is extremely variable in its anatomy. Indeed, a large number of frontal sinuses do not have true ducts connecting them with the frontal recess of the middle nasal meatus. In such cases the frontal sinus extends well down toward the nasal fossa and communicates directly by means of an ostium with the frontal recess. In a general way it may be stated when the frontal sinus develops by a direct extension of the frontal recess that its relations with the frontal recess in the adult will be more intimate. On the other hand, when the sinus develops from one of the anterior ethmoidal cells it will more frequently communicate with the frontal recess by means of a variable duct. It should, however, be stated that a goodly number of adult frontal sinuses with a genesis from anterior ethmoidal cells do not have nasofrontal ducts. Indeed, there are more frontal sinuses encountered in which true ducts of communication with the frontal recess are wanting than otherwise (Figs. 125 and 129).

The nasofrontal duct when present may be straight and short, or straight and relatively long. Again, it may be long and more or less tortuous or serpentine. Witness, for example, the specimen shown in Fig. 128, in which the nasofrontal duct is long, narrow and curved. It has very definitely two ostia frontalia, one proximal or nasal in position and the other distal or frontal. The duct is encroached upon by an anterior ethmoidal cell (really a second frontal sinus) which developed from the second frontal furrow. The slightest swelling of the mucosa of such narrow and tortuous nasofrontal ducts will, of course, occlude the passage of communication between the sinus and the nasal fossa.

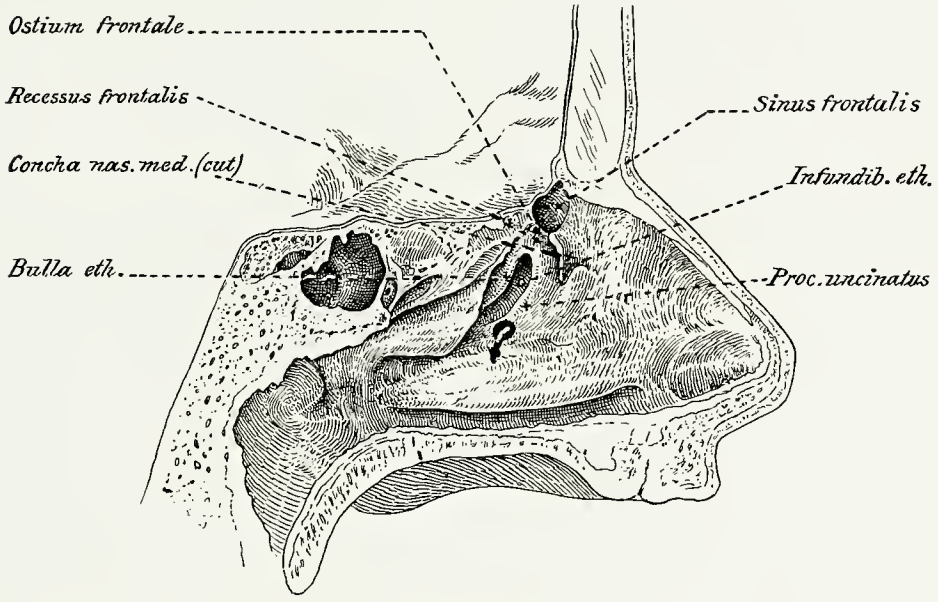

FIG. 129.—The lateral nasal wall of an adult, with a small frontal sinus and an absent nasofrontal duct. Indeed, the sinus is ethmofrontal and the anatomy such that one might consider the frontal sinus absent. It would not be reached by the usual Killian operation.

In some instances the nasofrontal duct is roomy and possesses large nasal and frontal ostia, thus affording a better drainage channel for the sinus. The efficiency of the duct is usually in direct ratio to its length, diameter and directness (Figs. 126 and 130).

The nasofrontal duct with its proximal or nasal ostium, or in the absence of a true duct the proximal ostium frontale (in the latter case there is no distal ostium frontale), bears a varied relation to the ventral extremity of the infundibulum ethmoidale. The latter usually ends blindly lateral to the terminal (nasal) portion of the nasofrontal duct. The ethmoidal infundibulum and the nasofrontal duct are at times in the

same axis (Figs. 124 and 197). Again, the nasofrontal duct with its proximal or nasal ostium is not in alignment with the ethmoidal infundibulum. Witness, for example, Fig. 126, where the proximal ostium frontale is located medial to the cephalic extremity of the processus uncinatus. Drainage in the latter instance would in a large measure be diverted into the middle nasal meatus directly. Moreover, one encounters specimens in which shallow gutter-like depressions on the lateral wall of the

FIG. 130.—The mucous membranes of the right frontal and maxillary sinuses exposed. Note the regular nasofrontal duct. The old term "infundibulum of the frontal sinus" applies well in this case.

frontal recess connect up the nasofrontal duct with the ethmoidal infundibulum. Such depressions must not be confused with the nasofrontal duct (Fig. 125). Finally, it is well to remember that occasionally the nasofrontal duct and the ethmoidal infundibulum are continuous channels. In the vast majority of instances, however, the nasofrontal duct and the ethmoidal infundibulum are discontinuous channels, save for a slight depression that occasionally extends between them.

Concluding Considerations.—In most cases in the first years of childhood, and in many instances in the adult, the frontal sinus owing

to its relations cannot readily be reached from the forehead. As pointed out elsewhere, in many young children and not infrequently in adults there is no frontal sinus in the squama frontalis (frontal or vertical portion of the frontal bone) or at best but sparsely developed in its base. In such cases the sinus is best exposed in the region where the frontal bone meets both the nasal bone and the frontal (nasal) process of the maxilla.

The clinician must bear in mind that there is no unvarying typical type of frontal sinus. Great variations are encountered. The prominence of the superciliary ridges or eminences (*arcus superciliares*) is very unreliable as an index of the location and extent of the frontal sinuses. Indeed, the author's studies and observations would seem to indicate that the ridges should be entirely ignored in clinical work. While it is true that the right and left sinuses are separated by a bony partition (*septum sinuum frontalium*), it is equally true that the dividing partition is rarely located in the mid-sagittal plane, save immediately dorsal to the nasal bones. Indeed, one or the other frontal sinus may occupy the whole frontal region, the septum being placed obliquely in both the semi-sagittal and semi-coronal planes, so that the larger sinus occupies a ventral position; that is, in front of the smaller sinus. This is important clinically, for a healthy sinus may be opened surgically on the opposite side, the diseased and sought sinus being dorsal to it. Moreover, it is easy to err in such cases by believing that a supernumerary frontal sinus is present when in reality it is merely an extension of the sinus belonging to the other side (Fig. 85).

Deficiencies or dehiscences in the osseous walls of the frontal sinus are of occasional occurrence. The defects are either congenital or pathologic in origin; others are the result of extreme pneumatization. The author finds that dehiscences in the orbital wall are the most frequent. The cerebral wall and the frontal or ventral wall above the supraorbital border (*margo supraorbitalis*) have been found defective in a few instances. But one specimen was found in which the inter-sinus septum was perforated, leading to a connection of the two sinuses. The dehiscences are either covered over with a mucoperiosteum or with a mucous membrane only. When the defect is a congenital one the periosteum apparently ends at the margin of the ostium dehiscence. The possibility of infection extending to the tissues of the orbit and to the meninges through such osseous defects must be kept in mind.

Partial septa of varying degree frequently project from the walls of the frontal sinus. They divide the cavity of the sinus incompletely into subcompartments, some of which not infrequently partake of the nature

of deep recesses and in consequence are drained with difficulty. The belief that these recesses at times form *enclosed cells* within the frontal sinus is, according to the writer's observations, unwarranted. It would appear that supernumerary frontal sinuses and impinging ethmoidal cells have at times been erroneously designated as "enclosed recess cells." Moreover, the olfactory fissure at times projects into the dorsomedial wall of the sinus as a bleb-like ridge. Care must be exercised in operative procedures lest the impinging olfactory fissure be broken into and the dura mater exposed to the infection. The impingement of the olfactory fissure is especially prominent when the dorsal portion of the inter-sinus septum is deviated to one side.

Agenesis of the frontal sinus is rare; duplication and triplication common. The diseased sinus may be the one dorsal in position and orbital in type (Fig. 120). The skiagram may not reveal it. In some cases the frontal sinus is entirely absent in the frontal or vertical portion of the frontal bone, but present and roomy in the orbital or horizontal portion, hugging closely the ethmoid labyrinth and extending far dorsad and laterad into the roof of the orbit. Indeed, in adults where the frontal sinus exists in duplicate of the type shown in Fig. 119 it may be necessary to open the ventral sinus to get to the one dorsal in position. The skiagram is of great value in determining the presence and extent of the frontal sinus in the region of the forehead, *e.g.*, in the vertical portion of the frontal bone. Where supernumerary frontal sinuses exist and where the sinuses are of the orbital type, even skiagraphy may furnish erroneous results. Of course, rhinoscopic examination is an invaluable supplement in the diagnosis. Electrical transillumination is unreliable.

In this connection it may not be amiss to quote briefly from Turner and Porter.[1] "Although the older method of investigating the frontal sinus by electrical transillumination undoubtedly possesses some value as a means of delineating the vertical portion of the cavity in the frontal bone, it frequently fails us when it is most desirable that we should obtain definite information as to whether the sinus is present or not. Further, it is quite useless as a means of ascertaining the existence of a horizontal or orbital extension of the cavity or for the purpose of defining its relations with the ethmoidal cells. If a frontal sinus exists it is possible to demonstrate its presence by skiagraphy, provided the picture is a good one and that the rays have passed through the head at the correct angle. Should the skiagram not be satisfactory, a second or even a third one should be taken in order to settle this point.

[1] The Skiagraphy of the Accessory Nasal Sinuses, Edinburgh, 1912.

If the rays have been incorrectly directed through the sagittal diameter of the head from a point too far above the external occipital protuberance a small frontal sinus may, in consequence, be invisible in the lower part of the frontal bone. If, on the other hand, the rays have been transmitted through the skull from a point some distance below that landmark, the ethmoidal cell may be projected onto the frontal sinus area and thus deceive us as to the true condition. Coakley[1] has pointed out that a small frontal sinus lying parallel with the supraorbital margin may escape detection upon the skiagram. Apart from these faulty or exceptional conditions, if a frontal sinus exists the anteroposterior skiagram will reveal it, and if there should be any doubt in the observer's mind a profile view of the head will prove of further assistance. From time to time the surgeon has operated upon the frontal sinus area and found that the cavity was absent; with a preliminary use of the X-rays, this mistake should no longer be made."

In a general way, as stated in a previous paragraph, when the frontal sinus develops from an anterior ethmoidal cell—frontal or infundibular—the adult cavity will more frequently have a nasofrontal duct. The tortuosity of the duct will, of course, depend upon the location of the cell from which the sinus frontalis develops and upon the degree of development and disposition of neighboring ethmoidal cells. On the other hand, when the frontal sinus develops by a direct extension of the frontal recess there will, in all likelihood, be no nasofrontal duct and the sinus proper be in direct relationship and communication with the adult recessus frontalis of the meatus medius. The connection of the nasofrontal duct is, of course, dependent upon the genesis of the frontal sinus; usually, however, the frontal sinus communicates with the frontal recess of the middle nasal meatus.

The outlet of the frontal sinus is readily influenced by variations in the anatomy of the related parts and by inflammatory conditions. An asymmetrical nasal septum may encroach upon the frontal ostium or the terminal portion of the nasofrontal duct. The size and disposition of the anterior group of ethmoid cells likewise have an important bearing. Enlargement of the uncinate process and the ethmoidal bulla frequently encroach upon the ethmoidal infundibulum and the semilunar hiatus and secondarily affect the outlet of the frontal sinus. A large middle nasal concha, because of its relationship, readily impinges upon the site of the frontal outlet. Then, again, the whole middle meatus may be so narrowed toward the frontal region that the space is insufficient for good frontal drainage. The latter may be the condition in apparently normal noses.

[1] Annals of Otology, Rhinology and Laryngology, 1905.

The well-known clinical fact that the sinus maxillaris (antrum of Highmore) is frequently a cess-pool for drainage from the frontal region of the meatus medius, doubtless leads to the erroneous belief that the infundibulum ethmoidale is, in the majority of instances, *directly continuous anatomically* with the nasofrontal duct or, in the absence of the latter, directly with the sinus frontalis. *It should, however, be pointed out, despite the fact that direct anatomical continuity is uncommon, from a clinical viewpoint in as many as* 50 *per cent. of adult cases the relationship is so intimate between the infundibulum ethmoidale and the sinus frontalis or its duct (ductus nasofrontalis) and certain of the anterior ethmoidal cells (some infundibular, others frontal) that drainage from these paranasal chambers finds its way in whole or in part into the infundibulum ethmoidale, thence via the latter to the ostium maxillare and through it into the sinus maxillaris.*

If in those cases in which the sinus frontalis (or its duct) is directly continuous anatomically with the ventral extremity of the infundibulum ethmoidale the ostium maxillare should occupy the greater portion of the floor of the infundibulum ethmoidale (a condition encountered) the frontal sinus and certain of the anterior ethmoidal cells (frontal and infundibular) would, anatomically and clinically, be in direct communication with the sinus maxillaris.

Intranasal opening of the frontal sinus for the purpose of drainage in chronic suppuration is now deemed feasible and is attended with no greater risk than is the extranasal operation. As stated before, the surgeon must continually bear in mind that the ventral portion of the ethmoidal labyrinth is intimately related with the sinus frontalis and that both of these paranasal chambers present great variations. X-ray examinations are of great help in determining the anatomy of the particular field. Moreover, certain landmarks, *e.g.*, the concha nasalis media, the processus uncinatus, the bulla ethmoidalis and the entrance to the recessus frontalis are fairly constant in their location and are of aid to the operator in the intranasal approach of the sinus frontalis. The proximal or nasal ostium of the frontal sinus is usually located in the recessus frontalis, and is related ventrally to a crest on the sinus surface of the ectal table of the frontal bone; dorsally to the ethmoidal labyrinth; laterally to the anterior cellulæ ethmoidales located between the ostium and the lacrimal bone; and medially to the nasal process of the frontal bone. It is, of course, obvious that ethmoidal cells must be ablated in establishing good drainage for the sinus frontalis and that the surgical approach is more direct than is the natural and often tortuous nasofrontal connection. Moreover the latter is not infrequently closed by inflammatory states of the mucous membrane.

V—THE SINUS SPHENOIDALIS

CHAPTER V

THE SINUS SPHENOIDALIS

The Fetal Stage

The sphenoidal sinus (sinus sphenoidalis) primarily arises in relation with the posterior cupola or dome of the cartilaginous nasal capsule and is genetically demonstrable as early as the fourth month of fetal life. The cupola-shaped recess or terminal nasal sinus (sinus terminalis), above referred to, is poorly developed in man; yet is, strictly speaking, the primitive sphenoidal sinus. The wall of the terminal sinus gives the foundation for the sphenoidal turbinal or concha (ossiculum Bertini). The actual bone arises through ossification which begins in the fifth month of fetal life as two primary and several secondary centers (see page 43).

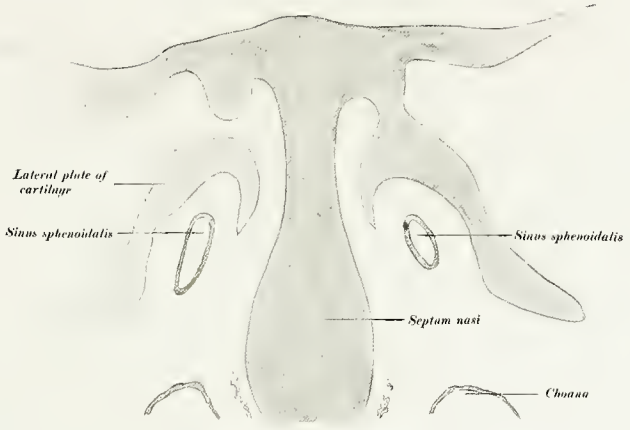

Fig. 131.—Outline drawing of a frontal section through the dorsal portion of the nasal cavity. × 10. Human embryo, aged 120 days.

It must be clearly understood that no portion of the fetal sphenoidal sinus is contained within the sphenoid bone. It is necessary that resorption of the intervening nasal capsule takes place before the terminal nasal sinus (early sphenoidal sinus) can come into actual contact with the body of the sphenoid bone. Indeed, such resorption does occur subsequently. In a certain sense, therefore, the fetal sphenoidal sinus is a constricted portion of the nasal fossa. The proximal end of the constriction remains as the ostium of the sinus and is always located cephalic to the highest nasal concha that may be present in the particular case.

The average sphenoidal sinus of the term fetus has a capacity of from 6 to 8 cubic mm., measuring approximately 2 by 2 by 1.5 mm. The ostium sphenoidale varies in diameter from 0.5 to 1.5 mm.

The Childhood Stage

Even in infancy the sphenoidal sinus continues to be nasal in position rather than sphenoidal. However, by the end of the third year the rudiment of the sphenoidal sinus is surrounded by bone save ventrally toward the nasal fossa where an opening, the *primitive ostium sphenoidale*, exists. During the fourth year the superior and medial parts of the

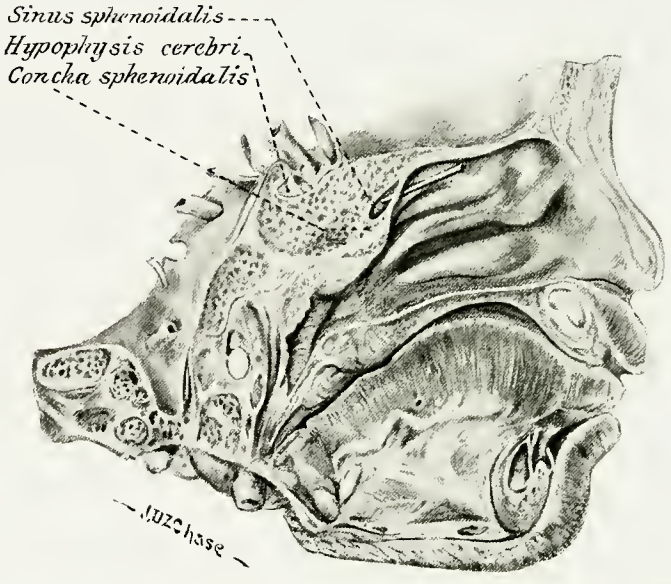

Fig. 132.—A sagittal section through the sphenoidal sinus of a child aged 18 months. Particularly note that the sphenoidal sinus does not occupy any portion of the sphenoid bone proper at this age, but is distinctly related to the sphenoidal concha or ossicle of Bertin. × 0.9.

bordering nasal capsule are resorbed and the body of the sphenoid bone allowed for the first time to bound the terminal nasal sinus (the primitive sphenoidal sinus). The superior and lateral parts of the sphenoidal concha (bony capsule) are also resorbed. This resorption causes the ostium sphenoidale in the sphenoidal turbinal to be notched instead of rounded. Later the inferior part and those portions partially surrounding the ostium sphenoidale of the turbinal in question fuse with the ethmoid bone and the body of the sphenoid bone. This gives the primitive sphenoidal sinus (sinus terminalis) opportunity to grow into and pneu-

matize the body of the sphenoid bone in the production of the definitive sphenoidal sinus.

The sphenoidal sinus in early childhood is more precocious than one would infer from divers statements in the literature. It is well known that in its initial growth into the body of the sphenoid bone the sinus has a marked tendency to develop in the dorsolateral plane at the expense of its direct ventrodorsal growth. This leads to an early thinning of the lateral wall of the sinus and to relatively thick septal and dorsal walls. Indeed, the dorsolateral aspect of the sphenoidal sinus may thus early come into intimate relationship with the ophthalmic and maxillary nerves and be a potent factor in childhood neuralgias of the trigeminal nerve,

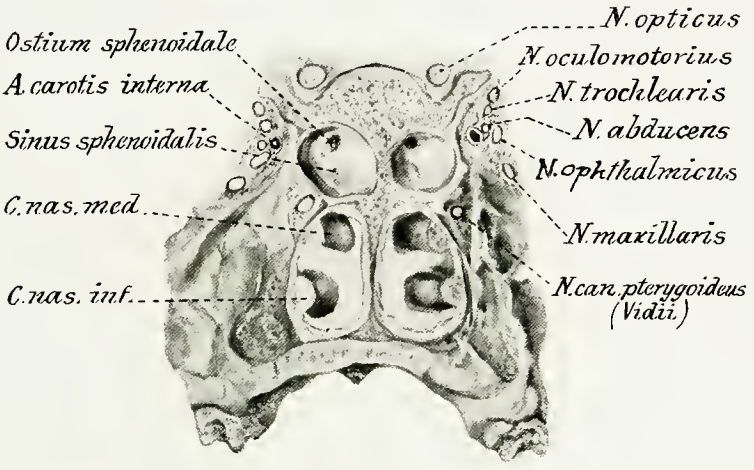

FIG. 133.—A frontal section through the nasal fossæ and sphenoidal sinuses of a child aged 7 years. × 0.8.

even as early as the third year. Moreover, the pterygoid (Vidian) canal with its contained nerve and vessels likewise early—sixth or seventh years—establish close relationship with the developing sphenoidal sinus (see page 320). It is obvious that the sphenoidal sinus is early of importance clinically and that by the second or third year has assumed proportions sufficiently large to become the seat of pathologic processes and to retain infectious material in its cavity. Table I indicates the growth of the sphenoidal sinus during the childhood period, *e.g.*, from birth to puberty.

The distance of the ostium sphenoidale from the cribriform plate of the ethmoid bone varies from 2 to 5.5 mm. There is no constancy in size of the ostium, the writer finding it to vary from 1 × 1 mm. to

3.0 × 3.5 mm. in a limited, but graded series of specimens of the childhood stage.

TABLE I

Age	Side	In millimeters		
		Cephalocaudal (height)	Mediolateral (width)	Ventrodorsal (length)
1st yr.	R	2.5	2.5	1.5
	L	2.5	2.5	1.8
2nd yr.	R	4.0	3.4	2.0
	L	4.0	3.5	2.0
3rd yr.	R	5.5	4.0	2.5
	L	5.2	4.0	2.8
5th yr.	R	7.0	6.5	4.5
	L	6.5	6.8	4.8
7th yr.	R	11.0	7.5	8.0
	L	11.0	7.0	7.0
9th yr.	R	15.0	12.0	10.0
	L	14.5	11.5	11.0
11th yr.	R	14.0	13.0	16.0
	L	8.5	10.0	8.5
14th yr.	R	15.0	10.0	12.0
	L	14.0	14.0	8.0

THE ADULT STAGE

General Considerations.—The adult sphenoidal sinus occupies a more or less central position in the skull and varies to an unusual degree in size and shape.[1] It is commonly located in the ventral and cephalic part of the body of the sphenoid bone. However, very frequently the paired sinuses pneumatize the entire sphenoidal body, even extend into the basilar process of the occipital bone and into the pterygoid processes and lesser wings of the sphenoid. Moreover, the sinuses not infrequently extend in the form of recesses into the superomedian aspect of the orbit, especially into the orbital process of the palatal bone (palatal sinus), into the anterior and posterior clinoid processes and bases of the greater wings of the sphenoid bone and into the ethmoid bone. Of course, not all of the recesses are necessarily present in the same specimen. Frequently there is marked asymmetry, giving rise to a prominent recess into one or other neighboring point. Rarely the rostrum of the sphenoid is invaded.

The recesses of the sphenoidal sinus are of great clinical importance since they encroach variously upon the *foramen rotundum* with the contained maxillary nerve; the *foramen ovale* with the mandibular nerve;

[1] The plaster casts of the sphenoidal sinuses by Dr. Hanau W. Loeb are valuable and instructive in this connection. The reader is referred to Dr. Loeb's Operative Surgery of the Nose, Throat and Ear, St. Louis, 1917.

and the *superior orbital* (sphenoidal) *fissure* with the ophthalmic, oculomotor, trochlear and abducent nerves, etc. (Fig. 195). When the lesser wing and the anterior clinoid process are partially hollowed out, the sphenoidal sinus encroaches upon the optic nerve, and if the pneumatization is extensive the nerve lies, in a sense, within the cavity of the sphenoidal sinus. The clinical importance of this relationship cannot be overestimated (Figs. 140 and 197). Very frequently, indeed, the body of the sphenoidal sinus is so hollowed out toward and into the bases of the pterygoid processes that the pterygoid or Vidian canal with the contained nerve (Vidian) and vessels throw the floor of the sinus into a ridged relief. In many cases the nerve and vessels are separated from the mucous membrane of the sinus by the merest shell of bone. Indeed, osseous dehiscences may be present (Figs. 139 and 195).

The author has encountered not a few cadavers in which the sphenoidal sinus not only pneumatized the entire ventral portion of the body of the sphenoid bone, but extended beyond into the palate and ethmoid bones in the formation of palatine and ethmoidal recesses. Indeed, in a number of instances one or more posterior ethmoidal cells were entirely replaced by such sphenoidal-sinus extensions. The latter may be sufficiently extensive to be bounded by the ethmoid, palate and maxillary bones and to establish immediate relationship with the maxillary sinus—a shell-like lamella of bone alone intervening between the mucous membranes of the respective sinuses (Figs. 135 and 136). Rarely the sphenoidal sinus extends sufficiently far into the pterygoid process of the sphenoid bone to come in contact with the wall of the maxillary sinus. Rarely the ethmoidal extension of the sphenoidal sinus is found to be in actual contact with the supraorbital extension of the frontal sinus.

The *pterygopalatine* (sphenomaxillary) *fossa* intervenes between the osseous boundaries of the sphenoidal and maxillary sinuses and precludes intimate relationships between the two sinuses at this point, and any extension of the sphenoidal sinus to come into contact with the maxillary sinus must either be over the sphenopalatine fossa, then in front of it, or dorsal and inferior to the fossa, as is the case when the pterygoid process is hollowed out. The pterygopalatine fossa is normally the angular interval between the pterygomaxillary and the inferior orbital fissures, and, as stated above, occupies the space between the maxilla in front and the root of the pterygoid process behind. Medially the perpendicular plate of the palate bone and nasal mucous membrane separate the fossa from the nasal cavity. However, the osseous medial wall is deficient, containing as it does the sphenopalatine foramen. The latter lies between

the orbital and sphenoidal processes of the palate bone and the inferior surface of the body of the sphenoid. The roof of the sphenopalatine fossa is formed by the inferior surface of the body of the sphenoid and the orbital process of the palate bone. The fossa contains on its dorsal wall the orifices of the pharyngeal canal, the pterygoid canal (Vidian) and the foramen rotundum, from within outward. Caudally the fossa contains the superior opening of the pterygopalatine canal together with the orifices of lesser palatine canals (Figs. 135 and 145).

The sphenopalatine fossa with its contained sphenopalatine (nasal, Meckel's) ganglion is obviously very intimately related with certain of the paranasal chambers which pneumatize the aforementioned osseous boundaries. Practically always the sphenoidal sinus is located immediately over the fossa and the ganglion, and when the sphenoidal sinus extends recess-like into the pterygoid process it gains an intimate dorsal relationship as well. Again, when the sphenoidal sinus extends forward into the ethmoid bone and orbital process of the palate bone there may be even a sphenoidal-sinus relationship to the sphenopalatine fossa ventrally. Usually, however, the maxillary sinus and one or more posterior ethmoidal cells are the paranasal chambers related ventrally to the sphenopalatine fossa with its contained ganglion. It is, therefore, very clear that the sphenopalatine ganglion is continually subjected to the influences of the very intimately related paranasal sinuses, particularly the sphenoidal. The nasal fossa is, of course, in constant relationship (Fig. 195).

Not infrequently a posterior ethmoidal cell (or cells) grows into the body of the sphenoid bone at the expense of one or both sphenoidal sinuses; indeed, may largely or entirely replace one or both of them. Such ethmoidal extensions into the body of the sphenoid bone are, however, readily distinguished from true sphenoidal sinuses since they never communicate with the sphenoethmoidal recess—the constant position for the aperture of the sphenoidal sinus (*ostium sphenoidale*). These ethmoidal-cell extensions into the sphenoid bone may be referred to as ethmosphenoidal cells. The cells at times overlie the sphenoidal sinuses so that the latter appear in sections as duplicated or triplicated (Fig. 141). The location of the ostia is, of course, the deciding factor in the classification. Moreover, it is especially the uppermost of such posterior ethmoidal cells that come into such very intimate relationship with the optic nerve, optic commissure, and even with the hypophysis cerebri (Fig. 155).

The Topography of the Adult Sphenoidal Sinus.—The paired sphenoidal sinus is located in what may be termed the danger position in the skull. Occupying a more or less central position dorsal to the cephalic portion

of the nasal cavity, it comes into intimate relationship dorsally with the hypophysis cerebri and not infrequently with a portion of the brain stem; laterally, with the dural cavernous sinus and its contained and related structures; cephalically, with the optic commissure and frequently with the hypophysis cerebri; caudally, with the Vidian nerve, the choanæ (posterior nares), and the nasopharynx; ventrolaterally, with the optic nerve and the ophthalmic artery. The relationships of the optic commissure and the hypophysis cerebri to the sphenoidal sinus are variable and dependent upon the degree of pneumatization of the body of the sphenoid (vide infra).

The *ventral wall* of the sphenoidal sinus projects dorsalward and caudalward, forming an obtuse angle at its junction with the cribriform plate of the ethmoid. The wall is usually relatively thick below and

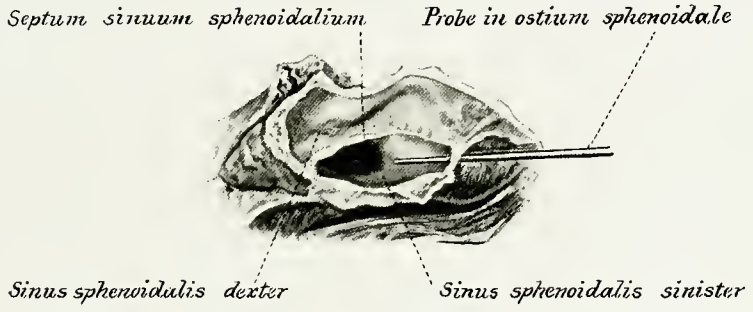

FIG. 134.—A sagittal section through the sphenoidal sinuses. Note the horizontal position of the septum of the sphenoidal sinuses and that the sinuses are really superior and inferior to each other rather than right and left. (Compare with Figs. 141, 142 and 159.)

frequently of extreme delicacy as it nears the cribriform plate. Clinically, the ventral wall is the most important of the sinus boundaries because it contains the aperture of the cavity (ostium sphenoidale, see page 187). The size of the nasal surface of the ventral wall of the sphenoidal sinus is largely dependent upon the depth of the sphenoethmoidal recess. When the latter is deep the aperture of the sinus is, as a rule, farther removed from the mid-sagittal plane. Posterior ethmoidal cells and the dorsal extremities of certain ethmoidal conchæ bear various relationships to the ventral wall. By following the olfactory sulcus, the roof of the nasal fossa, and the upper portion of the ventral sphenoidal wall, the aperture or ostium of the sphenoidal sinus is readily located (see page 97).

The *lateral wall* of the sphenoidal sinus participates in bounding the middle cerebral fossa and comes into immediate and direct relationship with the dural cavernous sinus and the contained structures (see page 193).

Moreover, the lateral is usually one of the thinnest walls of the cavity, often reduced by extensive pneumatization to a papery delicacy. Indeed, osseous dehiscences are not infrequently found. In surgical procedures it is, therefore, necessary to work with care on the lateral wall of the sphenoidal sinus. Curetting seems to be contraindicated because of the intimate relationships with the cavernous sinus and the frequent osseous defects, whereby the sinus mucosa is in direct contact with the dural wall of the vascular sinus (Figs. 195 and 197).

The *dorsal wall* of the sphenoidal sinus is usually relatively thick and less subject to variation as compared with the other walls. However, not infrequently one encounters specimens in which the sphenoidal sinus has pneumatized beneath and dorsal to the sella turcica, leading to an extremely thinned-out dorsal wall. This variation must be borne in mind in operative procedures, because the wall is readily broken through, and the basilar artery and pons immediately dorsal subjected to injury (Figs. 175 and 195). Further mention will be made of this relationship in connection with the hypophyseal-sphenoidal relations (page 188).

The *cephalic wall* of the sphenoidal sinus is extremely variable in its contour, thickness and extent. It is usually composed of thin, compact bone; however, may contain a considerable amount of cancellated bone between two compact lamellæ. The contour and extent of the cephalic wall are largely dependent upon the degree of pneumatization of the sphenoid bone and the shape, position and size of the sella turcica (Figs. 146 and 154). Moreover, osseous defects are occasionally encountered whereby the sinus mucosa and the ectal layer of the dura mater are in actual contact. Conforming with the size of the sphenoidal sinus, the relations of the intracranial structures vary. However, the hypophysis cerebri and the optic commissure are fairly constant in some form of relationship to the cephalic wall (see page 188).

The *caudal wall* of the sphenoidal sinus has its mid-point approximately over the choana (posterior naris), being half nasal and half pharyngeal in location. Not infrequently, owing to marked asymmetry, one or the other sphenoidal sinus is superimposed over both the right and left choanæ or posterior nares (Fig. 135). It varies from 2 to 13 mm. in thickness, according to a series of specimens investigated. This wall was at one time used as an approach to the sphenoidal sinus, via the buccal cavity. The ascending palatine artery (a. palatina ascendens, pharyngo-palatine artery), a branch of the external maxillary (facial) artery, crosses the lateral angle of the ectal surface of the caudal wall of the sphenoidal sinus and is here endangered in surgical procedures in the neighborhood. The

floor of the sphenoidal sinus may be so hollowed out that the nerve of the pterygoid canal (Vidian nerve) is at best separated from the sinus mucosa by a tissue-like plate of bone. Indeed, as stated elsewhere, the osseous canal may be defective here and there, thereby exposing the Vidian nerve and vessels to the direct influences of the outside air (Fig. 195). See also page 320 for a consideration of the Vidian nerve.

Not infrequently in the extension of the sphenoidal sinus into the pterygoid process of the sphenoid bone and into the perpendicular plate of the palate bone and the lateral mass of the ethmoid bone there is marked encroachment upon the confines of the pterygopalatine fossa (see page 318) with its contained structures, *e.g.*, the sphenopalatine ganglion, etc.

The *medial wall* of the sphenoidal sinus is the inter-sinus septum referred to on page 187. Dehiscences of this wall have been reported; however, the author encountered no such defect in a large series of healthy specimens. The medial wall is usually asymmetrical in location and not infrequently inclines in a semi-horizontal plane instead of its more usual vertical and semi-sagittal position (Figs. 134, 135, and 159).

Partial Osseous Septa and Recesses of the Sphenoidal Sinus.—While it is true that many sphenoidal sinuses have even and regular interior osseous walls, it is equally true that of all the paranasal sinuses the sphenoidal presents with the greatest frequency the most irregular walls (Fig. 195). Crescentic partial osseous septa are extremely commonplace. These vary from slight elevations to bridge-like osseous barriers which incompletely divide the sinus into subcompartments. Indeed, these septa are at times very misleading in sections of the sphenoidal sinus, since multiple sinuses are simulated in certain planes of section. Serial sections, of course, demonstrate the true anatomy; that is, that the septa are incomplete and but partially divide the sinus. The irregularities form recesses which in many cases obviously must retain infectious material despite the establishment of good drainage surgically. In some cases it would seem necessary to break down some of the recesses. However, the operator must bear in mind that these recesses and diverticula often have extremely thin outer walls and that there is danger of spreading the infection intracranially and intraorbitally by breaking into these cavities. Moreover, related structures are endangered (see elsewhere).

As stated elsewhere, entirely apart from the recesses formed by the very common partial osseous septa the sphenoidal sinus not infrequently pneumatizes extensively into the greater and lesser wings of the sphenoid, into the orbital plate of the palate bone, into the ethmoid bone and into the pterygoid process. Recess extensions into the pterygoid processes are

always fraught with danger since they form deep pockets in the floor of the sphenoidal sinus and cause the dependent portion of the sinus floor to be still farther from the aperture of the sphenoidal sinus (Fig. 139). As stated elsewhere, the aperture—ostium sphenoidale—is at best very disadvantageously located for efficient drainage and in this regard parallels the ostium of the maxillary sinus, *e.g.*, the ostium maxillare.

Sphenoidal Sinus Diverticula.—Diverticula of the sphenoidal sinus may be divided into two groups: (1) the recess-like extensions of the sphenoidal sinus into outlying portions of the sphenoid bone and into bordering bones, the osseous boundaries of such diverticula or recesses being complete; (2) mucosal diverticula or evaginations through dehiscences in the osseous wall of the sphenoidal sinus, the osseous boundaries of such diverticula being wanting.

1. The recess-like extensions of the sphenoidal sinus in which mucoperiosteum and bone participate as boundaries were referred to in the previous paragraph and will be dealt with at greater length in subsequent paragraphs. They can, therefore, be ignored in this connection.

2. Zuckerkandl, Onodi, Spee, Meyer and others have reported defects in the osseous lateral wall of the sphenoidal sinus. The writer likewise made similar observations and reported at length concerning them at an Anatomical Seminar at Cornell University in 1910. Many of these defects or dehiscences merely lead to such a condition whereby the mucous membrane of the sphenoidal sinus comes in direct contact with the ectal layer of the dura mater. At times, however, the mucous membrane evaginates hernia-like through an osseous defect or dehiscence. The author observed two such specimens in the Cornell University collection and a third in the Yale University collection. All three were unilateral. These mucosal diverticula or herniæ protruded for variable distances—3.5 and 5.5 mm.—into the epidural space by crowding the dura mater ahead of them. One of the mucosal diverticula projected into the cavernous sinus by pushing the ectal or outer layer of the dura mater bag-like into the lumen of the sinus.

Meyer observed a specimen in which there was a defect in the ventral portion of the lateral wall of the right sphenoidal sinus immediately beneath its roof. Through this osseous opening, oval in shape, protruded a diverticulum of the sinus mucosa, 6 mm. long, into the subdural space. The wall of the diverticulum was exceedingly thin and extended forward and upward into a triangular space bounded by the optic nerve anteromedially, the carotid artery posteromedially and the reflection of the dura mater laterally. The dura surrounded the base of the diverticulum on

all sides but, contrary to the author's specimens, did not envelop or cover the mucosal fundus. The dura merely came in contact with the mucosa at the margin of the osseous defect. In other words, the dura mater as well as the bone was deficient, permitting the sphenoidal-sinus mucous membrane to protrude through them. The mucous membrane or the sphenoidal diverticulum extended, thereby, directly into the subdural space and must have been in direct contact with the arachnoid.

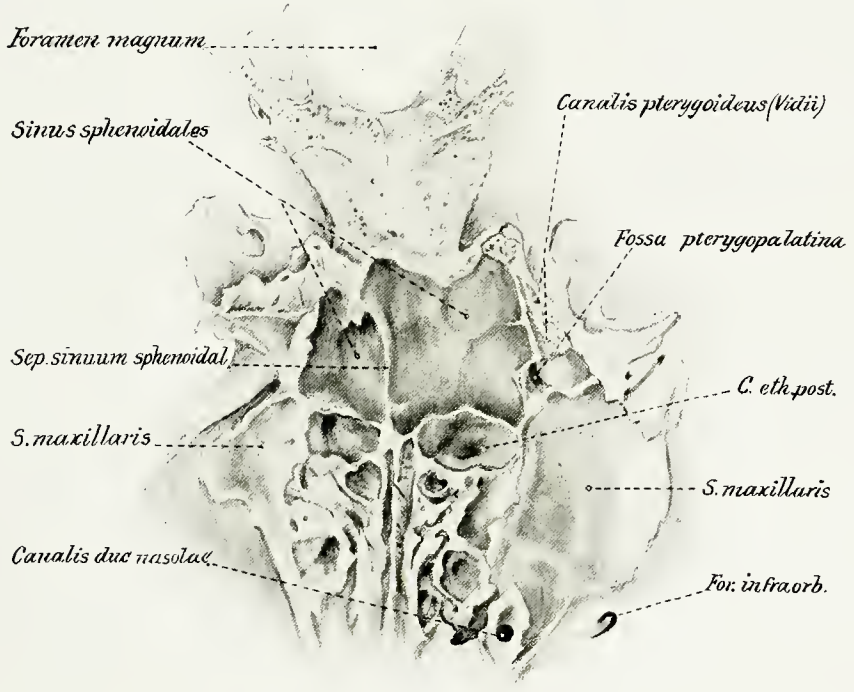

FIG. 135.—A basal dissection of the sphenoidal and maxillary sinuses. Particularly note that the right sphenoidal sinus has pneumatized forward into the ethmoidal region and established an immediate relationship with the maxillary sinus, a thin lamella of bone alone intervening. Note also the asymmetry of the sphenoidal sinuses.

The ventral half of the lateral wall of the left sphenoidal sinus contained a similar defect to that in the right sinus. A diverticulum of mucous membrane protruded through the oval defect for a distance of 3.5 mm. and extended across the dural reflexions over the optic and oculomotor nerves and enlarged slightly distally. The relations of the diverticulum to the surrounding structures were exactly the same as in the diverticulum from the right side. The diverticulum measured 6 mm. in length and 7 mm. in width.

Surely dura mater must have covered these diverticula at the time of their initial outgrowth from the sphenoidal sinus. However, at the time of observation the dura mater was perforated and the diverticula in actual relationship with the arachnoid. Why the dura mater should be perforated is, indeed, difficult to explain. The more likely thing would seem for the dura to be pushed in advance of the evaginating diverti-

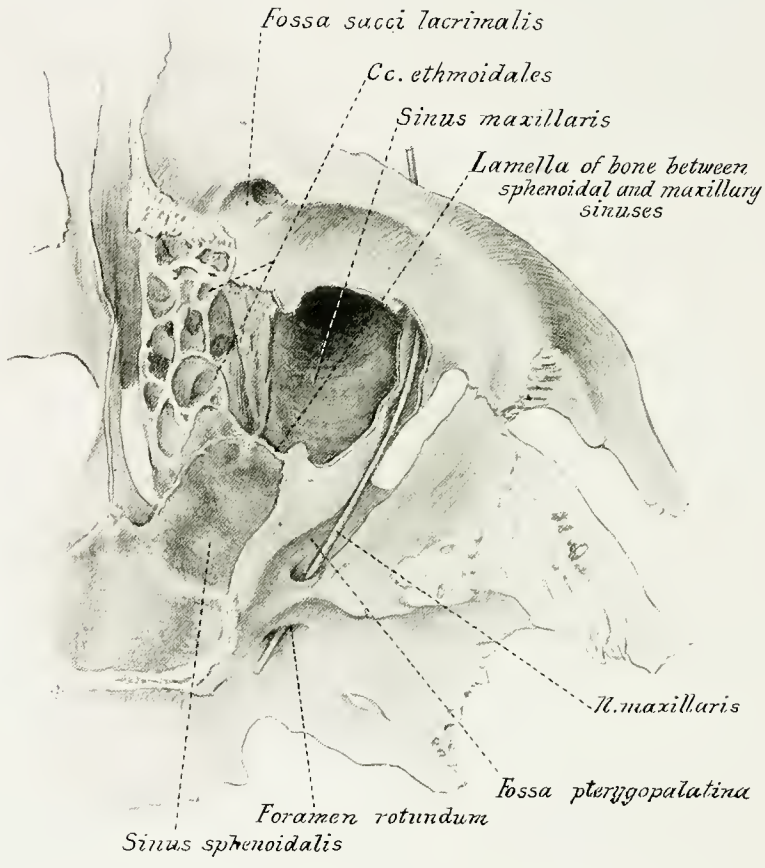

FIG. 136.—A dissection showing a marked extension of the sphenoidal sinus forward into the ethmoidal field, replacing certain posterior ethmoidal cells, to come into immediate relationship with the maxillary sinus. This unusual relationship is of importance clinically.

cula. Of course, the basal dura mater is extremely adherent and in all likelihood is perforated with greater ease by the growing mucosal sac than crowded away from its bony attachments.

Clinically, dehiscences in the osseous wall of the sphenoidal sinus are significant and when such defects lead to mucosal diverticula (in a sense, mucosal herniæ), which come in relationship anatomically with the

subdural space and the dura and arachnoid maters, they become even more important.

The Sphenoidal Septum (the septum sinuum sphenoidalium).—The paired sphenoidal sinuses are separated by a septum of variable thickness and location. The thickness is largely dependent upon the degree of pneumatization or size of the sinuses. The intersphenoidal septum may be placed more or less vertical and in the median plane throughout. More frequently, however, it is placed either to the right or to the left of the mid-sagittal plane, save ventrally where it is usually in line with the septum nasi. This leads to asymmetrical sphenoidal sinuses. Indeed, the septum may be placed obliquely in a semi-horizontal plane so that the right and left sinuses are in a sense cephalic and caudal in relation to each other. According to the writer's studies, the sphenoidal sinuses never normally communicate with each other due to a defective septum. However, such communications have been observed in pathologic states.

A few cases have been reported in which the inter-sinus septum was believed to be wholly absent, the two sinuses being represented by one large cavity with a single ostium. The writer, however, questions this interpretation and contends that the real condition is an agenesis of one sinus, thus allowing the single sinus to develop beyond the mid-line in pneumatizing the body of the sphenoid. The single ostium supports this view. Indeed, it is not uncommon for one sinus to be enormously developed and for its mate to be a mere rudiment. The latter might lead to the belief that the sinus is wholly wanting. Careful analysis, however, usually reveals the diminutive sinus (Figs. 134, 136, 141, 143, 144 and 159).

The Sphenoidal Ostium.—The sphenoidal ostium (ostium sphenoidale) or orifice of the sphenoidal sinus is always located on the dorsal wall of the sphenoethmoidal recess, therefore, cephalic to the uppermost ethmoidal concha that may be present. The right and left ostia are not necessarily on the same level. They are in most cases located slightly cephalic to the mid-plane of the ventral wall of the sinuses. There is, however, often marked deviation from this location as may be inferred from the measurements (in millimeters) given in Table J of a number of specimens selected from a larger series:

It is obvious from the following table that the ostium of the sphenoidal sinus is very disadvantageously placed for efficient drainage in case of empyëma of the cavity.

TABLE J

Side	Distance from center of ostium sphenoidale to roof of sinus	Distance from center of ostium sphenoidale to floor of sinus
R	12	17
L	10	13
R	12	12
L	12	9
R	2	3
L	16	13
R	2	20
L	12	17
R	3	6
L	12	4
R	15	17
L	17	16

Size of Sphenoidal Sinus.—The appended Table K of measurements (in millimeters) of a few specimens selected from a larger series shows the great variation in size of the sphenoidal sinus. Extremely rudimentary sinuses are encountered; again, enormous pneumatizations of the sphenoid bone are not uncommon, even extending beyond the body of the bone (Figs. 136 and 143).

TABLE K

Cadaver	Side	Cephalocaudal (height)	Mediolateral (width)	Ventrodorsal (length)
1	R	27	32	30
	L	21	28	28
2	R	5	3	3
	L	25	18	20
3	R	20	16	17
	L	18	10	14
4	R	34	14	18
	L	35	27	35
5	R	10	9	9
	L	21	27	22
6	R	19	12	18
	L	8	6	7
7	R	26	27	30
	L	16	12	20
8	R	23	34	43
	L	32	28	37
Averages		21.2	18.9	21.3

Conforming with the variations in size, the capacity of the sphenoidal sinus was found to vary from less than 0.5 cm. to 30 cm., with an approximate average of about 7.5 cm.

The Hypophysis Cerebri as Related to the Sphenoidal Sinus.—The hypophysis cerebri (pituitary body) is a small ovoid gland, flattened

cranio-caudally, and with its long axis directed transversely. It occupies the hypophyseal fossa (fossa hypophyseos, sella turcica), a deep depression over the middle of the superior (cephalic) surface of the body of the sphenoid bone. Dorsally the hypophyseal fossa is overhung by a sloping ridge, the dorsum sellæ, and ventral to the fossa is the olivary eminence (tuberculum sellæ). The hypophysis is roofed over by a spheroid pocket of dura mater—the diaphragma sellæ. The latter separates the hypophysis from the optic commissure and the optic tracts, which lie immediately cephalic (above) to it. The stalk (infundibulum) of the hypophysis penetrates the dura mater dorsal to the optic commissure and midway between the optic tracts. Laterally the cavernous sinus with the contained internal carotid artery comes into relationship with the hypophysis and the sphenoidal sinus.

The exact relations of the hypophysis to the sphenoidal sinuses must necessarily vary, since the shape and size of the sinuses are inconstant (Figs. 143, 146 and 175). In many cases the hypophysis is dorsal (posterior) to the sphenoidal sinuses and located much nearer the sinus roof than the floor. Not infrequently, however, the sphenoidal sinuses pneumatize the body of the sphenoid bone caudal (beneath) and dorsal to the hypophyseal fossa. When the latter anatomy prevails the hypophysis bears a dorsocephalic relationship to the sphenoidal sinuses. The thickness of the bone intervening between the sinuses and the hypophysis varies with the size and location of the sinuses.

The hypophysis may be exposed by an endonasal operation through the sphenoidal sinuses after first removing the ventral wall and the septum of the sinuses. Of course, when the sinuses are markedly asymmetrical, the removal of the septum may not be necessary, provided the operator selects the proper sinus in the approach. In order to expose some hypophyses the dorsal wall of the sinuses should be ablated immediately caudal (inferior) to the plane where the roof and dorsal walls are confluent (Fig. 146). However, when the sphenoidal sinuses have developed beneath the hypophyseal fossa with the contained hypophysis cerebri and dorsad toward (maybe into) the basilar process of the occipital bone, it is the roof and not the dorsal wall of the sphenoidal sinuses that must be ablated in order to expose the hypophysis cerebri (Fig. 195). In the latter, the anatomy is such that the operator could readily cut through the dorsal wall of the sinuses, miss the hypophysis altogether, and injure the basilar artery and brain (pons). Moreover, the operator must have due regard for the important structures located lateral to the hypophysis.

It is not the province here to discuss the detailed embryology, histol-

ogy and gross anatomy of the hypophysis cerebri, suffice it to say that it consists of three portions; the ventral, dorsal and intermediate portions. The ventral, glandular or buccal lobe usually embraces, cap-like, the smaller dorsal or cerebral lobe. The dorsal lobe is connected by means of the infundibulum with the tuber cinereum in the floor of the third ventricle. The latter often extends canal-like into the infundibular stalk for a considerable distance. The ventral lobe may be regarded as the functional portion of the hypophysis and the portion in most intimate relationship with the sphenoidal sinus.

Tumors of the hypophysis cerebri may encroach upon the lumina of the sphenoidal sinuses, even penetrate into the cavities. Encroachment on any of the surrounding structures may lead to serious results.

The Optic Nerve and Commissure (chiasm) as Related to the Paranasal (accessory) Sinuses.—It is essential that the intimate anatomic

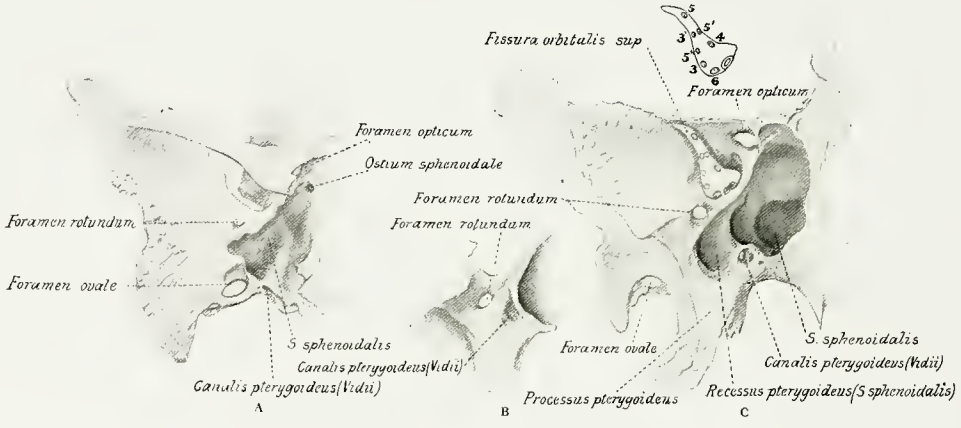

FIG. 137. FIG. 138. FIG. 139.

FIGS. 137, 138, 139.—In Fig. 137 note the extension of the sphenoidal sinus (dorsal exposure) into the great wing of the sphenoid bone with resultant intimate relations to the foramina rotundum (maxillary nerve) and ovale (mandibular nerve). Note also that the pterygoid or Vidian canal forms a conspicuous mound in the floor of the sphenoidal sinus.

In Fig. 138 note the relations of the foramen rotundum and the pterygoid canal when the sphenoidal sinus has not pneumatized into the pterygoid process of the sphenoid bone.

In Fig. 139 note the extensive prolongation of the sphenoidal sinus into the pterygoid process of the sphenoid bone (recessus pterygoideus), with a resultant wide separation of the foramen rotundum and the pterygoid canal (ventral exposure).

The inset illustrates the superior orbital (sphenoidal) fissure with contained strictures. 6 = abducent nerve; 4 = trochlear nerve; 5′ = frontal nerve; 5 = lacrimal nerve; 5″ = nasal nerve; 3 = inf. div. oculomotor nerve; 3′ = sup. div. oculomotor nerve.

relationships which exist between the paranasal sinuses and the optic nerve and commissure be understood by ophthalmologists and rhinologists. It is established that disease of the paranasal sinuses may lead to an optic neuritis, even to blindness. Of the paranasal sinuses, the sphe-

noidal and the posterior ethmoidal especially concern us in this connection (Figs. 140 and 155).

The optic nerve in its course from the eyeball to its juncture with the optic commissure pursues a more or less direct course dorsalward, medialward, and cranialward toward the apex of the bony orbit. At the apex of the orbit it is surrounded by the origins of the recti muscles, while in the orbit it is embedded by orbital fat. It traverses the optic foramen in the sphenoid bone in company with the ophthalmic artery—the latter, laterocaudal in relation to the nerve. Intracranially the optic nerve converges toward its fellow of the opposite side with which it forms a junction to form the optic commissure in the vicinity of the tuberculum sellæ (olivary eminence). The optic nerve varies from 32 to 55 mm. in length. Of this 25 to 40 mm. is intraorbital in position while the remaining portion is located in the optic foramen and the anterior cerebral fossa.

It is obvious when one recalls the direction of the optic nerves, far removed from each other distally and in confluence at the commissure, that the relations to the paranasal sinuses become more and more intimate as one passes from the eyeball toward the optic commissure. Indeed, for a considerable distance from the eyeball, the optic nerve is so far removed from the paranasal sinuses that very intimate relationship is precluded by the intervention of a considerable mass of orbital fat. However, as the optic nerve approaches the orbital apex and passes through the optic foramen to the optic commissure, very intimate relationships exist between some of the paranasal sinuses and the nerve and its commissure (Figs. 140 and 145).

The optic commissure bears a very intimate relationship to the sphenoidal sinus in the vast majority of cases. The exact relationships, however, vary with the size, shape, symmetry, and location of the sinuses. The commissure is frequently placed immediately cephalic (above) to the roof of one or both sinuses. In this connection it is well to recall that asymmetry is commonplace between the two sphenoidal sinuses. The thickness of the bone intervening between the sinuses and the optic commissure varies considerably, *e.g.*, from a papery delicacy to that of a substantial thickness. In approximately 50 per cent. of instances the optic commissure lies dorsal (posterior) in relation to the sphenoidal sinuses. As a rule, the posterior ethmoidal cells do not come into relationship with the optic chiasm. However, when the posterior ethmoidal cells grow into the body of the sphenoid bone intimate relationships are likewise established (Figs. 155 and 162).

The optic nerve pursues a course ventralward from the optic com-

missure along either the roof or lateral wall of the sphenoidal sinus. Frequently a posterior ethmoidal cell is more or less intimately related as well. After the optic nerve passes beyond the vicinity of the posterior ethmoidal cells, it diverges more and more from the ethmoidal field and is no longer in intimate relationship with the other ethmoidal cells.

The thickness of the bone between the optic foramen and contained structures and the cavity of the sphenoidal sinus varies according to the author's studies from 0.2 mm. to 2 mm., with an average of not over 0.5 mm. In very large sphenoidal sinuses the optic nerve joins the optic

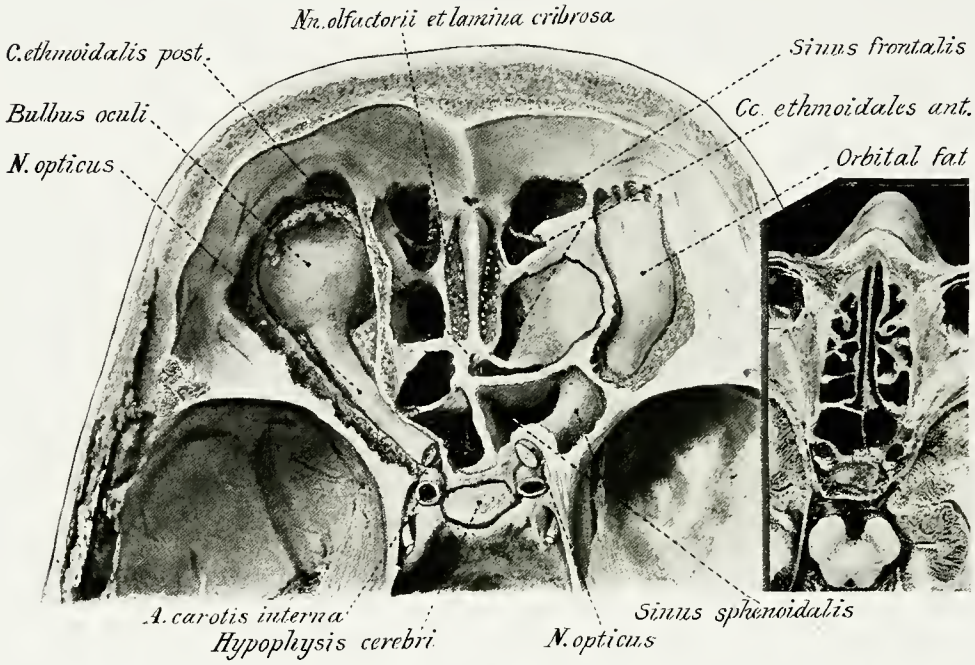

FIG. 140.—An exposure of the paranasal chambers from the anterior cerebral fossa. Moreover, the supraorbital walls have been removed, thereby exposing the optic nerve and eyeball. Particularly note the relationships of the right optic nerve and that the sphenoidal sinus extends beneath and over it, a thin lamella of bone alone separating the nerve from the sinus mucosa. On the left side the optic nerve bears a very common relationship to the sphenoidal sinus and a posterior ethmoidal cell.

The inset is a photograph of a transection of the ethmoidal labyrinth and sphenoidal sinuses. Note the larger number of individual ethmoidal cells as compared with the main figure.

commissure (chiasm) in the roof of the sphenoidal sinus some distance in advance of the dorsal wall of the sinus. This may apply to one or both sides. Opposed to this, in small sphenoidal sinuses the optic nerve usually joins the optic commissure dorsal to the sphenoidal sinuses (Fig. 144).

There is considerable variation in the distance between the caudal surface of the optic nerve and the ostium sphenoidale. The two sides

in this regard are frequently asymmetrical. Usually the optic nerve is cephalic to the level of the ostium sphenoidale. They may, however, be on the same plane or the reverse relationship may obtain, *e.g.*, the ostium be cephalic to the nerve. It is not uncommon for the nerve to be within 2 to 5 mm. of the ostium of the sphenoidal sinus. Again, a distance of 15 or more millimeters my intervene. The nerve is never more than a few millimeters caudal to the ostium of the sinus when such relationship exists.

Occasionally the sphenoidal sinus almost surrounds the optic nerve. Witness, for example, the specimen shown in Fig. 140 in which the sphenoidal sinus has developed beneath and over the optic nerve. Lateral to the optic nerve the two sinus extensions are separated merely by a thin lamella of bone. Moreover, the nerve is separated from the sinus mucosa by a thin, tubular mass of compact bone.

As mentioned previously, the most dorsal of the posterior ethmoidal cells frequently comes into intimate relationship with the optic nerve. This also applies with less frequency to the other posterior ethmoidal cells not in actual contact with the sphenoidal sinus. Not infrequently two or more posterior ethmoidal cells are in immediate relationship with the sphenoidal sinus instead of the more usual single cell. These cells may be arranged tier-like one over the other, the uppermost one establishing most intimate relations with the optic nerve and commissure (Fig. 145).

The frontal sinus, when of the supraorbital type and when well developed dorsomedially, may establish close relationships with the optic nerve, otherwise the latter does not bear important relations to the frontal sinus.

The maxillary sinus is separated from the optic nerve by the intervening osseous boundary and by a considerable amount of orbital fat and other structures. The relationship is, therefore, not intimate as a rule.

The Cavernous Sinus and Contained Structures as Related to the Sphenoidal Sinus.—The cavernous sinus is an endothelially lined channel contained within the dura mater and is traversed by irregular trabeculæ of fibrous tissue. This paired vascular sinus, of considerable size, extends along the lateral side of the body of the sphenoid bone from the superior orbital (sphenoidal) fissure to the apex of the petrous portion of the temporal bone. In this position the cavernous sinus with its contained structures is in intimate relationship with the sphenoidal sinus. The *internal carotid artery* and the *abducens nerve* traverse the sinus, while the *oculomotor*, the *trochlear*, the *ophthalmic* and the *maxillary nerves* are imbedded

in its lateral wall. Indeed, when the cavernous sinus is elongated dorsally the *mandibular nerve* may be in like relations. These nerves, save the abducens, lie in order from above downward and backward.

The abducens nerve in the region of the sphenoidal sinus is commonly located lateral to the internal carotid artery. The exact relationship depends upon the size and conformation of the sphenoidal sinus and the course of the internal carotid through the cavernous sinus. Not infrequently, indeed, the abducens nerve is located lateral to the internal carotid artery where the latter immerges into the cavernous sinus, then courses

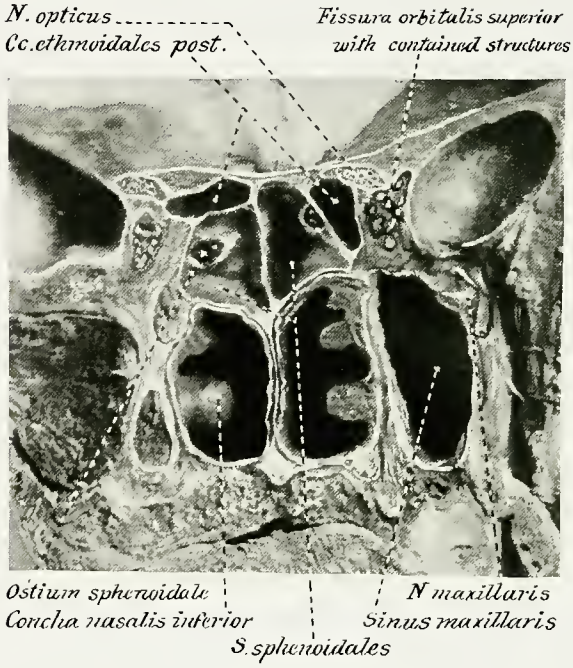

FIG. 141.—A coronal or frontal section through the head of an adult. Note the posterior ethmoidal cells extending into the sphenoid bone and encroaching upon the sphenoidal sinuses.

caudal to and parallels the artery for a greater or less distance, and finally again passes lateral to the artery as the latter assumes a final vertical course and the nerve emerges from the cavernous sinus into the orbit. The abducens nerve is, therefore, in very many instances in direct contact with the lateral wall of the sphenoidal sinus for a goodly portion of its course—dura mater and very thin bone intervening between the nerve and the mucous membrane of the sinus (Fig. 199). If osseous dehiscences exist in these cases the mucous membrane alone serves as a barrier between the abducens nerve and the outside air or any secretions that may be contained in the sinus. Moreover, when the sphenoidal sinus expands

into the ventral portion of the root of the great wing of the sphenoid bone, there is a corresponding encroachment upon the superior orbital (sphenoidal) fissure with again a sinus contact for the abducens nerve as the latter emerges from the cranial cavity through the superior orbital fissure into the orbit (Fig. 139). Again, the abducens nerve may come

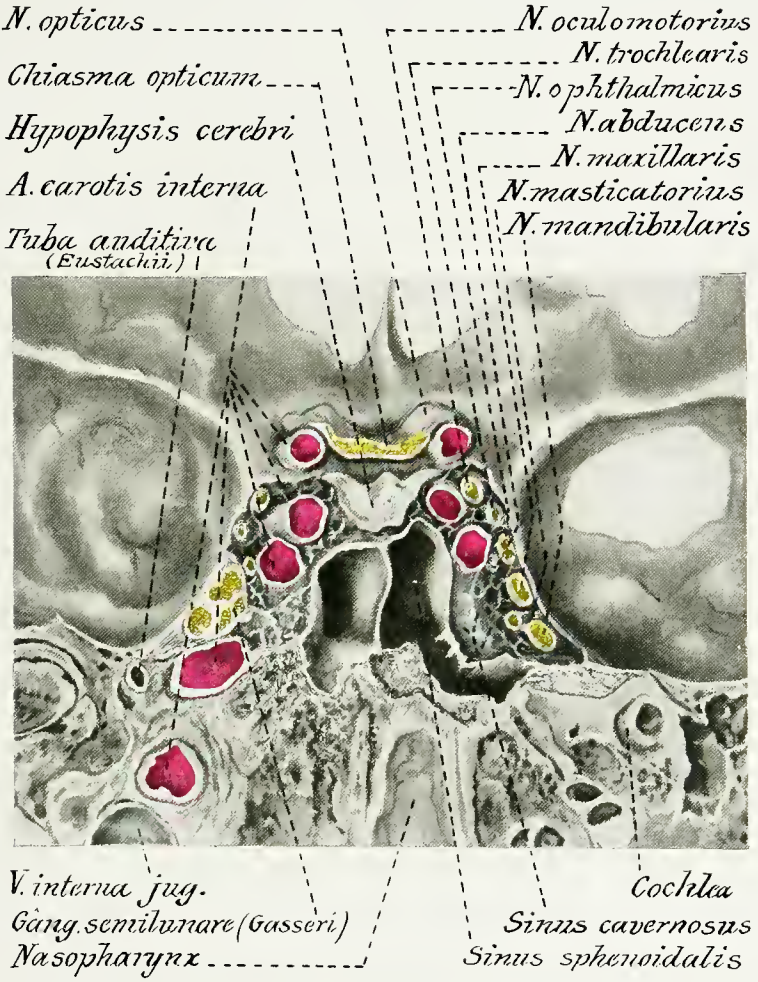

FIG. 142.—A dissection of the cavernous sinuses and related parts. On the right side the plane of section is oblique, while on the left side the plane of section is purely frontal. Particularly note the extension of the sphenoidal sinus of the right side beneath the cavernous sinus. It is in these cases that the Gasserian ganglion and the mandibular nerve come into relationship with the sphenoidal sinus; moreover, that direct relations with the temporal lobe of the brain are established.

in contact with the sphenoidal sinus dorsal to the internal carotid artery when the sinus pneumatizes or extends into the sloping surface of the body of the sphenoid bone dorsal to the hypophyseal fossa (clivus blumen-

bachii, Blumenbach's slope). Indeed, the oculomotor nerve likewise may be encroached upon in the latter extension of the sphenoidal sinus.

The internal carotid artery in its third or intracranial course ascends from the position of the foramen lacerum medium, where it escapes from the carotid canal, in the direction of the posterior clinoid process, soon, however, to bend forward and immerge into the dural cavernous sinus. It courses forward in the dural sinus accompanied by the abducens nerve on its lateral and caudal sides (see above), to again bend sharply upward at the level of the anterior clinoid process and emerge from the cavernous sinus by piercing its wall, *i.e.*, the dura mater.

In the vast majority of cases the internal carotid artery as it traverses the dural cavernous sinus pushes the lateral wall of the sphenoidal sinus into a conspicuous serpentine-like mound (Figs. 195 and 197). The prominence of the arterial relief is, of course, largely dependent upon the degree of lateral expansion of the sphenoidal sinus. However, not infrequently in relatively small sinuses is the relationship very intimate. The osseous wall intervening between the sinus mucous membrane and the dura mater and the internal carotid artery is very commonly of extreme delicacy. Indeed, congenital dehiscences or bony defects over the artery are of fairly frequent occurrence. In such cases the thin outer dural layer alone intervenes between the artery and the sinus mucosa (Fig. 195). As the artery emerges from the cavernous sinus, it courses very closely to the lateral side of the hypophyseal fossa, a relationship to be recalled in hypophyseal operations.

The almost constant and extremely intimate relationships of the internal carotid artery to the lateral wall of the sphenoidal sinus make operative procedures on this wall of the sinus exceptionally hazardous. Moreover, since the osseous barrier between the sinus and the artery is not infrequently deficient or at best but of a papery delicacy, it would appear that any procedure involving cutting or curretting to be unwarranted. In addition, the very common irregularities on the lateral sphenoidal wall must not be forgotten as well as other structures often as much exposed as the internal carotid artery; for example, the abducens nerve.

In conclusion it may be said that the intimacy of the relationships between the structures contained in the cavernous sinus and the sphenoidal sinus is dependent upon (1) the extent of the cavernous sinus and (2) the degree of pneumatization of the body of the sphenoid bone and the extensions of sphenoidal-sinus recesses and diverticula into neighboring parts. If the sphenoidal sinus extends far dorsolaterad, the semilunar ganglion (Gasserian) and the mandibular nerve may be intimately related.

If the root of the lesser wing of the sphenoid bone is partially hollowed out, the optic foramen and nerve are encroached upon. The maxillary nerve comes into intimate relationship with the sphenoidal sinus when the latter grows in the direction of the foramen rotundum—a very common condition (Fig. 195). Indeed, the maxillary nerve may be in close proximity

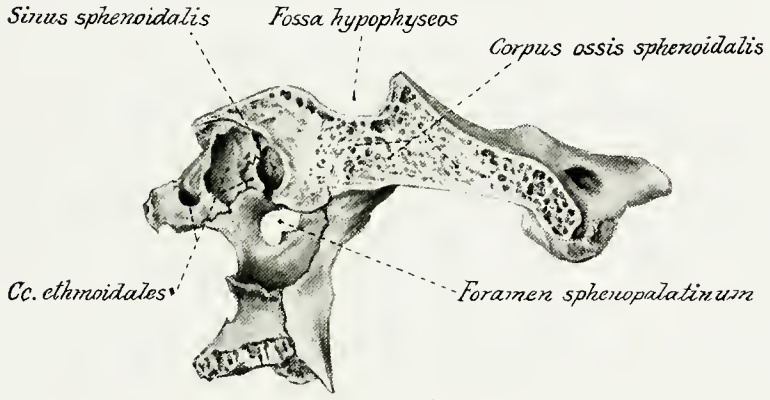

FIG. 143.—A sagittal section of a very small sphenoidal sinus from an adult. The intimate relations that usually exist between the sphenoidal sinus and the hypophysis cerebri, the cavernous dural sinus and the related structures are precluded in specimens of this sort. (Compare with Fig. 197.)

to the sphenoidal sinus as early as the third year. The sphenoidal sinus very commonly encroaches upon the confines of the superior orbital (sphenoidal) fissure and because of this establishes intimate topographical

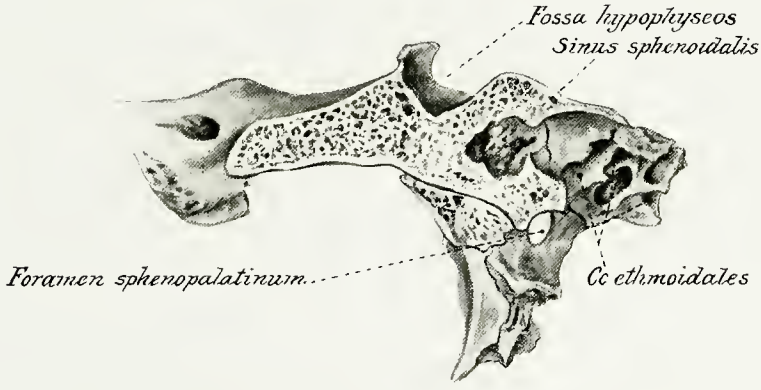

FIG. 144.—A sagittal section of the body of the sphenoid bone, etc. Note the exceptionally small sphenoidal sinus and its remote relations to the hypophyseal fossa. From an adult, aged 50 years.

relationships with the structures that are transmitted by it, et cetera (Fig. 139).

Diminutive Sphenoidal Sinuses.—Very small sphenoidal sinuses are now and then encountered. The walls are proportionately thick and pre-

clude the very intimate relations between the sphenoidal sinus and the neighboring structures previously referred to (Figs. 143 and 144).

Agenesis of the Sphenoidal Sinus.—Agenesis of the sphenoidal sinus is very uncommon according to the author's observations. Specimens were observed in which posterior ethmoidal cells pneumatized the body

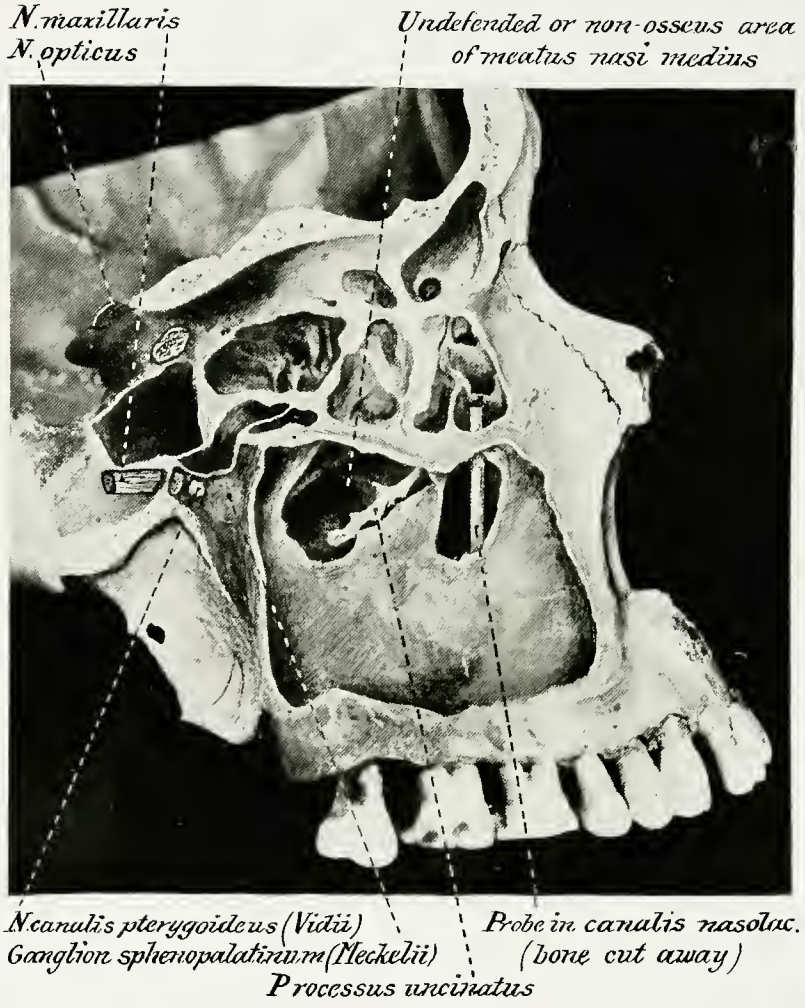

FIG. 145.—Paranasal chambers exposed from the lateral side. Note the projection of a posterior ethmoidal cell over the pterygopalatine fossa.

of the sphenoid bone, the sphenoidal sinuses proper being represented by mere rudiments on the ventrocaudal wall of the body of the sphenoid bone. Moreover, a few cases were encountered in which the body of the sphenoid bone was solid and wholly unpneumatized, save for very slight depressions

in wide communication with the sphenoethmoidal recesses on the ventral or nasal surface of the sphenoidal body.

Concluding Considerations.—It is well known that little, if any, information of value regarding the size of the sphenoidal sinus in infancy can be obtained from the skiagram. The solid body of the sphenoid bone throws too dense a shadow at an early postnatal period. Haike, however, differentiated the sphenoidal sinus in the skiagram at the age of $3\frac{1}{2}$

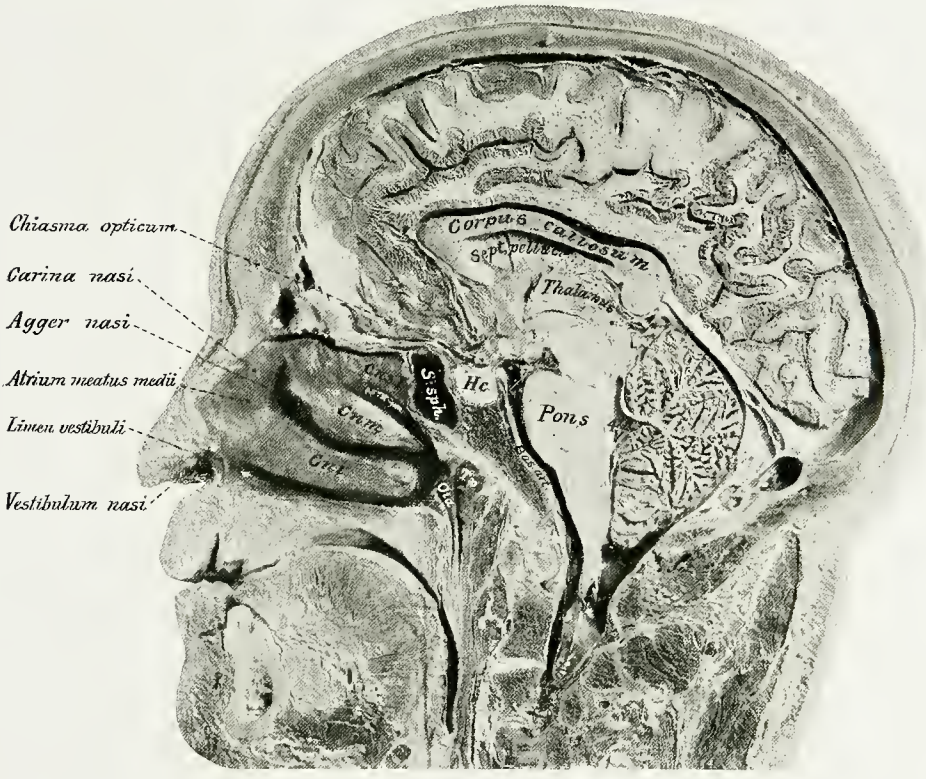

FIG. 146.—Photograph of a mid-sagittal section of the head of an adult body.

years, the cavity presenting a brighter area within the dark shadow of the body of the sphenoid. Turner and Porter throw out a caution in the interpretation of skiagrams of the sphenoidal region in very young people. They claim that one may be deceived by the lighter shadow presented by the cancellous tissue of the body of the sphenoid bone. The development and size of the sphenoidal sinus is ascertained to the best advantage by profile views of the head. A comparison between skiagrams and actual measurements of the sphenoidal sinus during the childhood period as given in Table I, page 178, is helpful in arriving at the size and shape of

the cavity at a given period. Haike cautions that operators must always remain conscious of the limitations of the skiagram, yet owing to the difficulty of endonasal investigations in the young child he hopes to obtain conclusive evidence from the skiagram alone. However, in older children he believes that one ought always to be guided more by the result of clinical examination than by the skiagram. Onodi likewise holds that the clinical signs be considered principally and the skiagram be used only as a secondary aid to diagnosis; moreover, believes that while this is true in general in connection with accessory sinus troubles, it is particularly applicable to diseases of the sphenoidal sinus in children. The sphenoidal sinus has been successfully treated by radical operation in children of 6 years of age. Onodi believes that resection of the sphenoidal sinus in the first years of childhood should be performed through the ethmoidal labyrinth.

In the adult, skiagraphy of the sphenoidal sinus is valuable in delineating the ventrodorsal size of the cavity and the thickness of the sinus walls. Of course, a profile skiagram is desirable. Moreover, the skiagram is valuable in diseased conditions, as a means of diagnosis and assistance in determining the anatomical contour and size of the sinus in a particular case. However, it is well known that the skiagram is of less anatomical assistance preliminary to operations in case of the sphenoidal sinus than it is in the frontal and maxillary sinuses. This is, however, not true in the sphenoidal approach of the pituitary body surgically. Roentgenography is indispensable in the establishment of the indications and in the operation itself. The radiogram clearly outlines the size of the hypophyseal fossa and its exact relation to the sphenoidal sinus. Moreover, it gives some evidence of the size of the sphenoidal sinus and the distance from the ventral surface of the sphenoid bone to the anterior nasal spine.

Pfahler[1] in 1916 described a new method of study of the paranasal or accessory sinuses with the roentgen rays. He employs a technic whereby a roentgen-ray film is inserted into the mouth and the roentgen-ray tube adjusted over the head so that the rays course more or less at right angles to the film. The method appears to be of especial advantage when skiagrams of the ethmoid labyrinth and sphenoidal sinuses are desired. The several paranasal sinuses appear in the picture in isolated positions with less overlapping than in other methods. This is, of course, of distinct advantage.

In disease of the sphenoidal sinus it is well to recall the intimate anatomic relations to important structures. Optic neuritis, even blind-

[1] Laryngoscope, July, 1916.

ness, may ensue. Infection of the sphenoidal sinus and the ophthalmic vein may lead to cavernous sinus thrombosis. Certain of the cranial nerves related to the cavernous sinus may be paralyzed. Ventrally the cavernous sinus receives as tributaries the ophthalmic vein and farther dorsad, occasionally, the basilar vein and veins from the related dura mater. Moreover, the two sinuses are interconnected. The blood is carried from the cavernous sinus by the two petrosal dural sinuses and by veins which leave its caudal surface to pass extracranially through the foramina in the sphenoid bone, etc. It is well known that the cavernous sinus may become infected from sources other than the sphenoidal sinus, *e.g.*, from foci far removed, especially through the extraorbital anastomoses of the ophthalmic veins. The anatomy is such that cavernous sinus infection and thrombosis may follow ulceration of the nasal mucosa, alveolo-dental periostitis, empyema of other paranasal sinuses, infections of the face, infections of diplöic tissue in the region of the forehead. Naturally, therefore, in obstruction to the blood flow through the cavernous sinus, as in thrombosis, there would be edema of the eyelids and side of the nose and upper face, and an exophthalmos; and if the structures that are related to or contained within the cavernous sinus should be involved, there would be ptosis, pupil irregularities, strabismus, pain, etc.

In curretting or cleaning pathological tissue from the sphenoidal sinuses, due regard must be had for the very important structures immediately ectal to the thin-walled sinus. In extensive pneumatization many or all of the structures mentioned may have the most intimate anatomic relations to the sinuses. Particularly would the author call attention to the cavernous sinus and internal carotid artery as structures readily injured, especially so in those cases where the osseous wall is deficient and the inner wall of the cavernous sinus in direct contact with the mucosa of the sphenoidal sinus. In case of the internal carotid artery the outer (ectal) dural layer alone would intervene between the vessel and the sinus mucosa. This is also frequently true for a short segment of the abducens nerve (page 194 and Fig. 197).

The Vidian nerve in the floor, the maxillary nerve as it traverses the foramen rotundum, and the optic nerve in its course through the optic foramen are the most constant nerves in intimate relationship with the sphenoidal sinus.

The auditive tube (tuba auditiva Eustachii) is as a rule too far removed from the sphenoidal sinus to become involved in sinus disorders unless the sphenoidal sinus extends its pneumatization extensively into the pterygoid process in the formation of the pterygoid recess (Fig. 139).

The latter may establish intimate anatomic relationships with the auditive tube and be a factor in infecting the mucous membrane of the tube, since the recess is so dependent and far removed from the aperture of the sphenoidal sinus that infectious materials are readily retained within its confines. The auditive or Eustachian tube extends, of course, between the nasopharynx and the tympanic cavity or middle ear. Moreover, the pharyngeal ostium of the auditive tube is always in juxtaposition to the dorsal extremity of the inferior nasal meatus and is, therefore, readily involved secondarily in certain disorders of the nasal fossa, since the mucous membrane is directly continued from the nasal fossa into the nasopharynx and from there into the auditive tube.

VI—THE ETHMOIDAL CELLS

CHAPTER VI

THE ETHMOIDAL CELLS

The Fetal Stage

The ethmoidal air cells (cellulæ ethmoidales) are primarily extensions or evaginations of the nasal mucosa from the middle, superior, and first supreme nasal meatuses; *e.g.*, from the meatuses directly or from the accessory furrows and recesses which configure their lateral walls, particularly the lateral walls of the middle and superior meatuses. The reader is referred to previous paragraphs concerning the early anatomy of the major

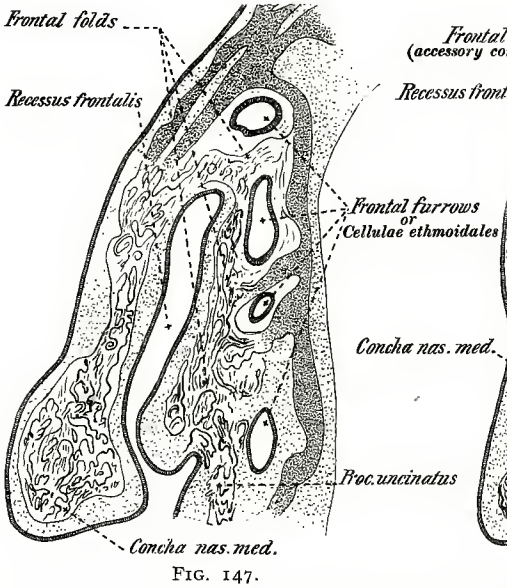

FIG. 147.

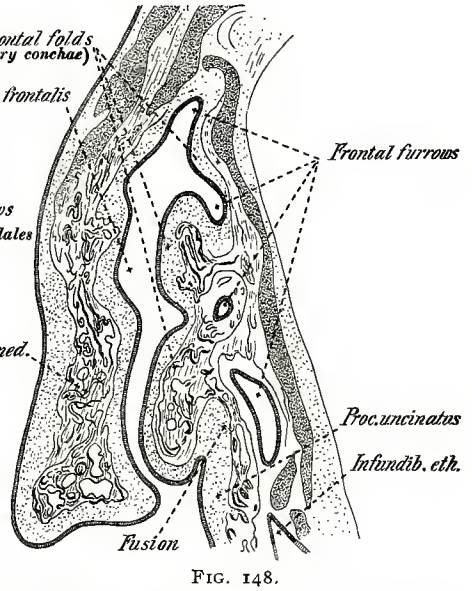

FIG. 148.

FIGS. 147–148.—Frontal sections through the frontal recess of a 7-month fetus. Section Fig. 147. is farther ventral than is section Fig. 148.

Note the blind ventral extremities of the frontal furrows in section Fig. 147. Strictly speaking these are early cellulæ ethmoidales anterior. In section Fig. 148, some of the furrows or cells are shown to be in free communication with the frontal recess. Any one of these cells may develop sufficiently far to become the frontal sinus. Indeed, we see here the potentials for multiple frontal sinuses. The frontal recess proper also frequently gives rise to the frontal sinus. × 10. (*After J. P. S.*)

meatuses and the accessory or secondary furrows and the major and secondary conchæ since they play such an important rôle in determining the location of the initial ethmoidal cells.

The initial ethmoidal out-pouchings are in evidence as early as the

fourth month of fetal life. For some time the surfaces of the mucous-membrane sacs are in many cases in contact and the lumina in a sense merely potential, again the early sacs may be mere dimple-like depressions. However, by the seventh month the evaginations have taken shape in the form of hollow tubular-like, blindly ending sacs, with ostia in communication with the points of initial outgrowth. These tubular sacs may now truly said to be ethmoidal cells. Horizontal sections of the nose of

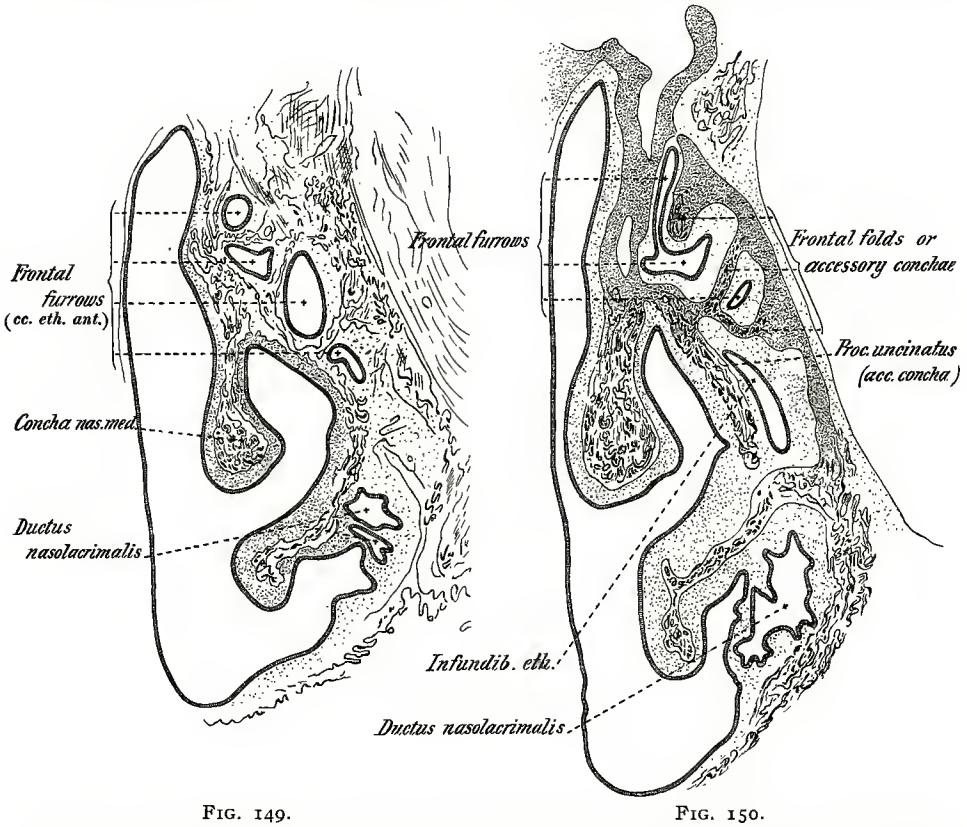

FIG. 149. FIG. 150.

FIGS. 149–150.—Drawings of frontal sections through the left nasal fossa in the region of the frontal recess. Note the early frontal furrows, rudiments of anterior ethmoidal cells. Fig. 149, from a term fetus, series *D*, slide 4; Fig. 150, from a 7-month fetus, series *B*, slide 31.

the term fetus show the ethmoidal cells considerably developed, the anterior group measuring on the average 5 × 2 × 3 mm. and the posterior group 5 × 4 × 2 mm. Reconstruction of the "term" ethmoidal labyrinth is a valuable method of study of the early stages.

THE CHILDHOOD STAGE

The lateral masses of the ethmoid bone and its appendages (the major and accessory conchæ) are primitively solid structures. Soon, however,

the lateral masses become more or less honeycombed or labyrinth-like by the developing ethmoidal cells. In the formation of the ethmoidal labyrinth there is no uniformity of development. In a general way the anterior group of the ethmoidal cells develop ventral to the posterior group. There is, however, at times considerable overlapping of the two groups. Each cell as it grows from a preformed furrow or recess tends more or less toward the cribriform plate of the ethmoid bone. Even though a certain cell has its anlage-point farther inferior than another cell, it may outgrow its neighbor and force the latter to progress in a direction other than toward which it was primarily directed, indeed, dwarf its growth. Later the cells in honeycombing the lateral ethmoidal masses grow in almost any direction. Cells that arise from unlike meatuses, never communicate with each other. Furthermore, a cell always communicates with the meatus from which it develops.

There is early a division topographically of the ethmoidal field into two groups: (1) *cellulæ ethmoidales anterior*, (2) *cellulæ ethmoidales posterior*. The anterior group develop from points caudal (inferior) to the attached border of the middle nasal concha and the posterior group from points cephalic (superior) to the attached border of the middle nasal concha. The so-called *cellulæ ethmoidales mediæ* (middle group) are here classed with the anterior group. This is a better classification since the cells which grow from the accessory furrows of the descending ramus of the middle nasal meatus (bullar furrows and infundibulum ethmoidale) are closely associated with the cells (the old anterior group) which grow from the ascending ramus (frontal recess and its furrows) of the middle nasal meatus and from the ventral and cephalic extremity of the infundibulum ethmoidale.

As stated previously, the frontal furrows on the lateral wall of the frontal recess vary in number. There may, indeed, be a total absence (Fig. 40); the frontal recess then appearing as a simple, blind outgrowth from the meatus medius. The furrows and recess develop variously into anterior ethmoidal cells, and, in addition, the frontal sinus in the majority of cases develops as an outgrowth from this region. Some of the furrows remain extremely shallow and never reach the dignity of ethmoidal cells. Indeed, regression is operative in some instances and some furrows may disappear altogether, either by a coalescence of bordering folds or otherwise. The agger nasi is very commonly pneumatized by the most ventral of the ethmoidal cells developing from the frontal furrows.

The infundibulum ethmoidale may terminate ventrally and superiorly by dilating into a single ethmoidal cell lateral to the frontal recess and its

derivatives. However, it is not uncommon to find from two to four cells growing out from its ventral extremity. These infundibular cells have varied relationships. Some may grow sufficiently far into the frontal bone to become frontal sinuses. Others may impinge upon the frontal sinus and produce bullar-like swellings on the sinus floor. Again, they grow into the agger nasi, the processus uncinatus, etc.

The bullar cells (the former middle ethmoidal cells) vary in number from one large cell to five or more smaller ones. In fully 95 per cent. of cases cells arise as extensions from the preformed suprabullar furrow and

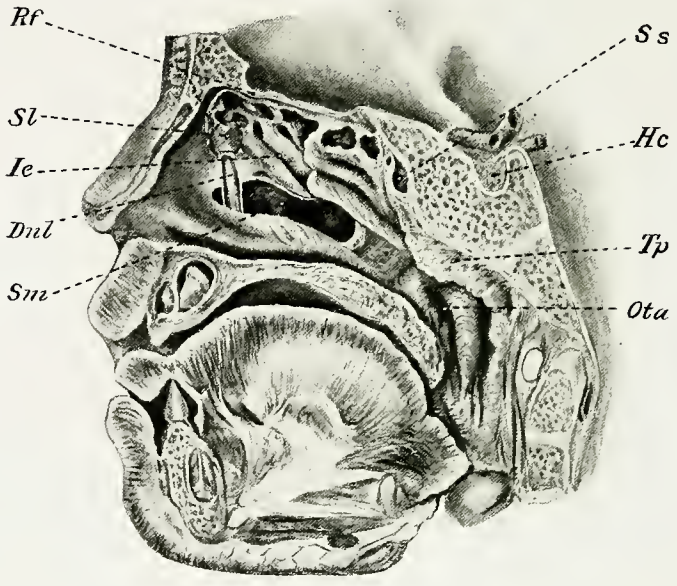

FIG. 151.—The paranasal sinuses in a child aged 16 months. The nasal wall of the maxillary sinus has been removed. Reduced.

Rf = recessus frontalis; *Sl* = saccus lacrimalis; *Ie* = infundibulum ethmoidale; *Dnl* = ductus nasolacrimalis; *Sm* = sinus maxillaris; *Ss* = sinus sphenoidalis; *Hc* = hypophysis cerebri; *Tp* = tonsilla pharyngea; *Ota* = ostium tuba auditiva.

in 12 per cent. of cases from the infrabullar furrow. Occasionally (8 per cent.) the bullar furrow gives rise to an ethmoidal cell. These cells early hollow out the accessory concha (bulla ethmoidalis) and frequently extend into the supraorbital plate of the frontal bone and into the infraorbital plate of the maxilla. Their size greatly influences the width of the infundibulum ethmoidale and the hiatus semilunaris, and incidentally the natural drainage channels of the maxillary sinus.

During childhood the posterior ethmoidal cells gradually pneumatize and make shell-like the superior and supreme conchæ. Even before puberty the cells may extend into the supraorbital plate of the frontal

bone and into the infraorbital plate of the maxilla. Indeed, the author has seen as early as the tenth year marked extensions into the body of the sphenoid bone and into the maxilla, the latter simulating a duplicated maxillary sinus. Such ethmoidal-cell extensions, however, never normally communicate with either the sphenoidal or maxillary sinuses. Even before birth one frequently sees extensions into the middle nasal conchæ. Growth of a posterior ethmoidal cell into the orbital process of the palate bone is, likewise, encountered (palatal sinus).

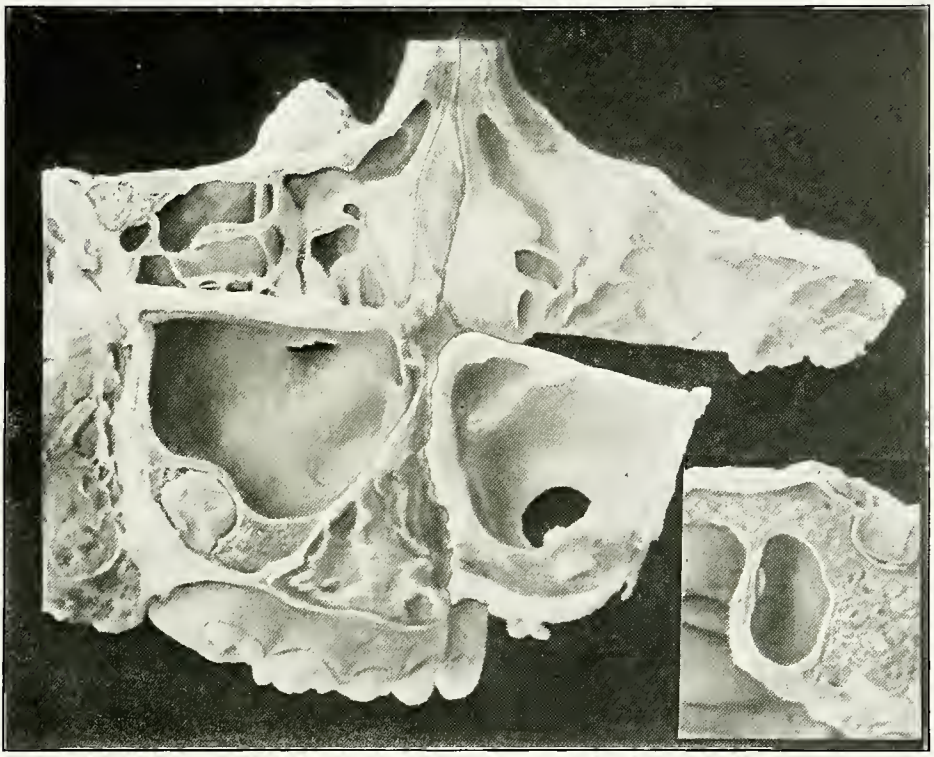

FIG. 152.—A photograph of a dissection of the paranasal sinuses of a child aged 8 years, 2 months and 10 days. The inset in the lower right-hand corner illustrates the sphenoidal sinus and its relation to the hypophysis cerebri. (Dissection by Dr. Warren B. Davis.)

It is well to remember that, owing to the relatively narrow nasal fossa, it is difficult to explore the ethmoidal field by the endonasal route in the young child. However, it must not be forgotten that even in early childhood both the anterior and posterior groups of ethmoidal cells are fairly well established and subject to diseases. Surgeons have radically operated upon the ethmoidal cells in the child through the maxillary sinus and by way of the frontal sinus. Meyer operated upon the ethmoidal labyrinth by way of the maxillary sinus in a child between 3 and

4 years of age. The skiagram is a valuable aid in the delineation of the ethmoidal field in the child, but its limitations must be kept in mind. The early frontal sinus may readily be confused with the ethmoidal cells. Haike, according to Onodi, believes "that a reliable diagnosis of ethmoidal affections in children can only be obtained by skiagraphy." However, he throws out the following caution: "In young children the picture of the ethmoidal cells in the skiagram is so narrow that it is sometimes difficult

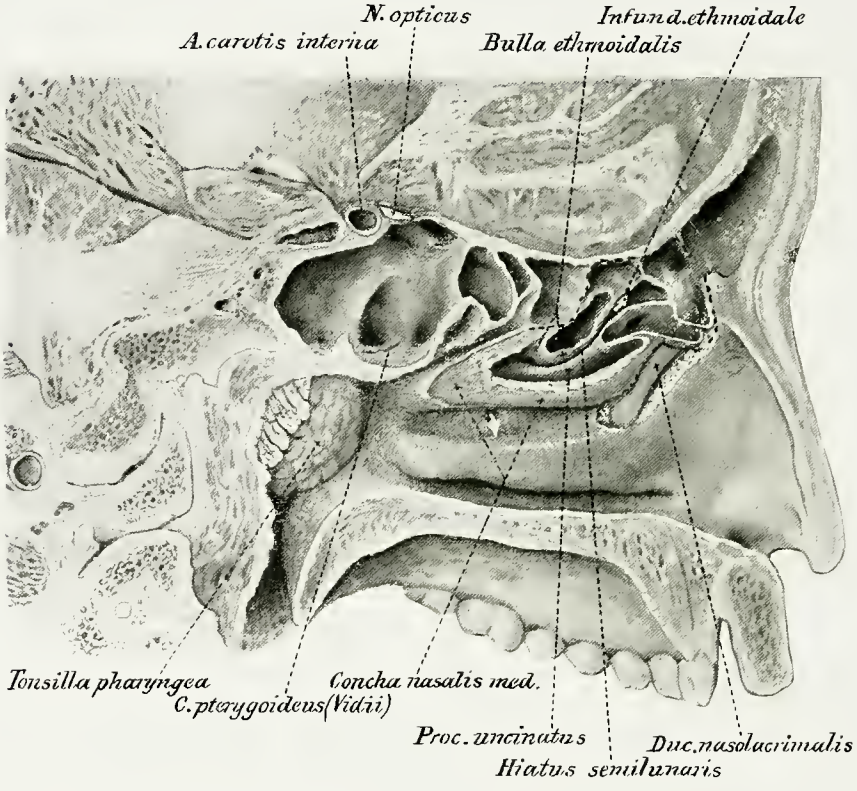

FIG. 153.—A dissection of the paranasal sinuses and the nasolacrimal duct of a male child aged 11 years. Note that the degree of pneumatization and the relation of the several paranasal chambers are essentially those of the adult. The Vidian nerve is intimately related to the floor of the sphenoidal sinus. The arrow in the middle nasal meatus indicates an accessory maxillary ostium.

to arrive at a definite diagnosis; thus, even moderate congestion of the mucous membrane may veil the lumina of the small ethmoidal cells. With regard to the question whether the anterior or posterior ethmoidal cells are affected, the skiagram can give no more information in children than in the adult."

Table L gives the size of the ethmoidal cells of the childhood period of a series measured by the author. Great variation is, of course, en-

countered and is to be expected among the several cells composing the ethmoidal labyrinth. The great discrepancy in the size of the cells at a given age is largely due to the great variability in the number of cells differentiated. The fewer the cells the larger will be the several measurements, since the ethmoidal labyrinth will occupy the entire ethmoidal field whether composed of few or many cells. The author found the number of cells to vary from *three* to *fifteen.*

TABLE L

Age	Group	Cephalocaudal, mm. (height)	Mediolateral, mm. (width)	Ventrodorsal, mm. (length)
Newborn	Anterior	5	2	2
	Posterior	5	4	2
1 year	Anterior	2–8	1.5–6	2-7
	Posterior	2–8	1.5–7	2-9
2 years	Anterior	3–9	2–6	2-6
	Posterior	5–8	3–4	4–6
5 years	Anterior	7–8	5–7	5–6
	Posterior	7–8	7–10	6–7
8 years	Anterior	8–11	7–10	6–7
	Posterior	8–11	7–10	9–16
10 years	Anterior	9–12	8–12	8–10
	Posterior	9–14	8–12	9–17
14 years	Anterior	9–16	10	5–23
	Posterior	9–15	14	8–20

THE ADULT STAGE

General Considerations.—The great complexity of the adult ethmoidal labyrinth and the variations in size, shape and disposition of the individual cells composing it are in accord with the early anatomy and potentialities of development.

The fully developed ethmoidal labyrinth occupies the field between the medial surfaces of the bony orbits and, generally speaking, extends between the frontal sinuses ventrally and the sphenoidal sinuses dorsally. Cephalically (above) the cribriform laminæ serve as the boundary planes, while the uncinate processes represent the caudal limit of the labyrinth. One must, however, bear in mind that almost constantly the ethmoidal labyrinth extends beyond one or more of the true boundaries of the ethmoidal field in the formation of ethmofrontal, ethmolacrimal, ethmomaxillary, ethmosphenoidal and ethmopalatine cells. Moreover, not infrequently, cellular extensions into the overhanging middle nasal concha (cellulæ conchales) extend the ethmoidal labyrinth below the level of the uncinate process.

The mesethmoid (lamina perpendicularis) divides the ethmoidal labyrinth into two more or less symmetrical and independent lateral halves. However, at times one or the other half is markedly enlarged at the expense of its fellow.

Classification.—The embryology and adult anatomy of the ethmoidal cells justify the classification appended in Table M.

As stated elsewhere the adult ethmoidal cells are seldom wholly confined within the ethmoid bone. Their osseous boundaries are variously completed by the articulation of the ethmoid with neighboring bones, *e.g.*, the frontal, lacrimal, sphenoid, palate, and maxilla. While in many cases related bones merely serve to complete the osseous outlines of ethmoidal cells at the planes of articulation, they not infrequently lodge extensive cellular outgrowths from the ethmoidal labyrinth. These extensions are particularly common into the supraorbital plate of the frontal bone and into the infraorbital plate of the maxilla. Moreover, the extension of posterior ethmoidal cells into the bodies of the sphenoid and maxillary bones, there encroaching upon the sphenoidal and maxillary sinuses respectively, must always be kept in mind when dealing with these sinuses. Indeed, the maxillary extension is often mistaken for a supernumerary maxillary sinus (see page 119 and Fig. 101). Extensions into the lacrimal and palate bones are frequent, but of less practical importance. The extension into the palate bone is often referred to as the palatal sinus. This is to be regretted because it implies an individual sinus when in reality it is nothing other than a part of the ethmoidal labyrinth.

Very commonly the anterior group of ethmoidal cells encroach upon the frontal sinus, even extend into the frontal bone to become topographically frontal sinuses (Fig. 118). Such cells frequently produce bullous-like elevations on the floor of the frontal sinus. They are frequently referred to as frontal bullæ (bullæ frontales). Furthermore, cells of the ventral group not infrequently grow into the middle nasal concha, the agger nasi, and the uncinate process.

It is impossible in very many instances to judge whether a cell belongs to the anterior or the posterior ethmoidal group merely from its position. It is the location of the ostium rather than the body of the cell that determines its classification; the anterior group draining into the middle nasal meatus and the posterior group into the superior and first supreme meatuses.

Dehiscences.—The osseous boundaries of the ethmoidal cells are not infrequently defective; particularly are dehiscences common in the orbital plate (os planum, lamina papyracea) of the ethmoid bone. The author

TABLE M.—CELLULÆ ETHMOIDALES

Primary groups		Secondary groups	Genetic areas	Communication in adult	
Cellulæ ethmoidales anterior	Of meatus nasi medius	Cellulæ frontales	(*a*) Frontal recess (*b*) Frontal furrows	Frontal recess of meatus nasi medius	Meatus nasi medius
		Cellulæ infundibulares	Infundibulum ethmoidale	Infundibulum ethmoidale	
		Cellulæ bullæ	Bullar furrows, especially the suprabullar and the infrabullar	Suprabullar furrow	
				Infrabullar furrow	
				Bullar furrow	
		Cellulæ conchales	(*a*) Meatus nasi medius	Meatus nasi medius (directly)	
			(*b*) Infundibulum ethmoidale	Infundibulum ethmoidale.	
			(*c*) Merely extensions of other anterior ethmoidal cells	Other anterior ethmoidal cells	
Cellulæ ethmoidales posterior	Of meatus nasi superior	Cellulæ superior	(*a*) Ventral extremity of the meatus nasi superior	Meatus nasi superior	
			(*b*) Recessus superior of meatus nasi superior		
			(*c*) Recessus inferior of the meatus nasi superior		
		Cellulæ conchales	(*a*) Ventral extremity of the meatus nasi superior	Meatus nasi superior (directly)	
			(*b*) Recessus inferior of the meatus nasi superior		
			(*c*) Merely extensions of other posterior ethmoidal cells	Other posterior ethmoidal cells.	
		Cellulæ supremæ I (of meatus nasi supremus I)	Meatus nasi supremus I	Meatus nasi supremus I	

Extraethmoidal Extensions of Cellulæ Ethmoidales: (*a*) Ethmofrontal, (*b*) Ethmolacrimal, (*c*) Ethmomaxillary, (*d*) Ethmosphenoidal, (*e*) Ethmopalatine

has likewise observed a number of specimens in which the mucous membrane of ethmoidal cells was in actual contact with the dura mater. The importance of these dehiscences in the spread of infection from the ethmoidal labyrinth to the tissues of the orbit and the meninges must ever be kept in mind by the clinician. Moreover, it is extremely common to find that the osseous wall between certain of the anterior ethmoidal cells and the lacrimal fossa is congenitally deficient, whereby the mucous membrane of the cells comes into actual contact with the lacrimal sac. It seems certain from the anatomy of the region that the nasolacrimal passageways must commonly suffer infection by a direct extension from the ventral ethmoidal labyrinth (see page 255).

Size of the Ethmoidal Labyrinth.—The accompanying Table N gives the size of the adult ethmoidal labyrinth and its subgroups as determined by several measurements of a number of specimens selected at random from a larger series. The discrepancy in the ventrodorsal

TABLE N.—THE ADULT ETHMOIDAL LABYRINTH
(All measurements are in millimeters)

		Cellulæ anterior			Cellulæ posterior			Labyrinth		
Number	Side	Cephalo-caudal	Ventro-dorsal	Medio-lateral	Cephalo-caudal	Ventro-dorsal	Medio-lateral	Cephalo-caudal	Ventro-dorsal	Medio-lateral
1	R	38	25	13	35	26	12	40	34	15
	L	40	14	12	38	23	13	41	32	13
2	R	19	10	6	16	18	11	17	27	11
	L	15	11	10	17	16	10	17	20	10
3	R	18	14	8	23	26	10	30	36	12
	L	34	25	16	30	25	15	35	35	16
4	R	21	22	7	20	28	28	20	36	13
	L	16	22	9	16	20	10	20	36	13
5	R	17	38	10	6	12	8	19	40	10
	L	17	32	10	12	15	8	19	32	12
6	R	30	20	18	25	23	12	36	34	18
	L	31	20	18	25	20	23	36	30	18
7	R	18	14	7	23	25	10	30	34	10
	L	34	26	15	31	25	13	30	32	15
8	R	17	38	9	7	12	7	20	48	17
	L	15	31	10	10	15	8	20	17	17
Average		23.6	22.6	11.1	20.8	20.5	12.3	26.8	32.7	14.0

diameter of the whole ethmoidal labyrinth as compared with the combined diameters of the anterior and posterior groups of cells, is due to the fact that there is considerable variation at the junction point of the two groups, particularly in the degree of overlapping. Usually the combined ventrodorsal diameters of the anterior and posterior ethmoidal groups exceed

FIG. 154.—A dissection of the paranasal sinuses exposed from the lateral aspect.

the ventrodorsal diameter of the ethmoidal labyrinth measured as a whole. The difference between the measurements of the right and left sides is insignificant according to this series. Now and then isolated cases, however, show a marked difference.

The Anterior Ethmoidal Cells (cellulæ ethmoidales anterior).—The anterior ethmoidal cells vary in number from *two* to *eight* in the

series of specimens studied. They invariably communicate by individual ostia with some portion of the middle nasal meatus under cover of the middle concha. The size of the individual cells is in a large measure dependent upon the number of cells that are differentiated in a particular case, the fewer the number the larger the cells, and vice versa (Figs. 127 and 140).

Genetically the anterior group of ethmoidal cells is clearly divided into three main subgroups. In the adult, however, the position of the individual cells is often misleading if one would judge the classification from the position of the cell alone. It is, therefore, the location of the ostium of the cell and not the topography of the cell itself that determines the subclass. From the standpoint of the location of ostia, the anterior ethmoidal cells may be divided into: (*a*) cells communicating with the frontal recess; (*b*) cells communicating with the ethmoidal infundibulum; and (*c*) cells communicating with the region of the ethmoidal bulla, usually the suprabullar recess.

The frontal group of the anterior ethmoidal cells vary in number from a total agenesis to three or four. Developmentally they are outgrowths from the furrows on the lateral wall of the frontal recess (preethmoidal recess of some writers). Not infrequently one or more of these cells encroach upon the lumen of the frontal sinus to such an extent that they are ethmofrontal cells. Indeed, at times they are in reality frontal sinuses as far as topography is concerned. The floor of the frontal sinus is very commonly crowded into a bullous relief by frontal ethmoidal cells (Fig. 118). Another common extension of a frontal cell is into the upper portion of the agger nasi (Figs. 153 and 159). Other cells remain small and topographically are in relationship with the frontal recess only and in this regard retain their genetic location.

The frontal group of the anterior ethmoidal cells variously impinge upon the nasofrontal duct or in the absence of the latter upon the ostium of the frontal sinus. Not infrequently they cause the nasofrontal duct to pursue a tortuous or serpentine course; moreover, so restrict the duct and ostium of the frontal sinus that its drainage is very much impaired (Fig. 128). The individual cells of the frontal group usually communicate rather freely with the frontal recess immediately cephalic and ventral to the termination of the semilunar hiatus of the ethmoidal infundibulum. They are located between the lateral surface of the lamella of the middle nasal concha, the ventral and medial surface of the ethmoidal bulla, and the medial wall of the bony orbit. It is particularly these cells that must be ablated in the endonasal surgical approach of the frontal sinus.

The infundibular group of the anterior ethmoidal cells all grow from the ethmoidal infundibulum and in the adult are always in communication with it. They vary in number from a total absence to three or four. In a large percentage of cases the ventral and cephalic extremity of the ethmoidal infundibulum ends blindly by dilating into an anterior ethmoidal cell (infundibular) lateral to the frontal recess and its related cells (Fig. 124). Another very frequent outgrowth from the ethmoidal infundibulum is into the agger nasi which usually more or less overlies the lacrimal sac, and in the endonasal surgical approach of the lacrimal sac (dacryocystorhinostomy) it is usually opened into before the lacrimal bone is reached in the operation (Figs. 159 and 175). Infundibular cells

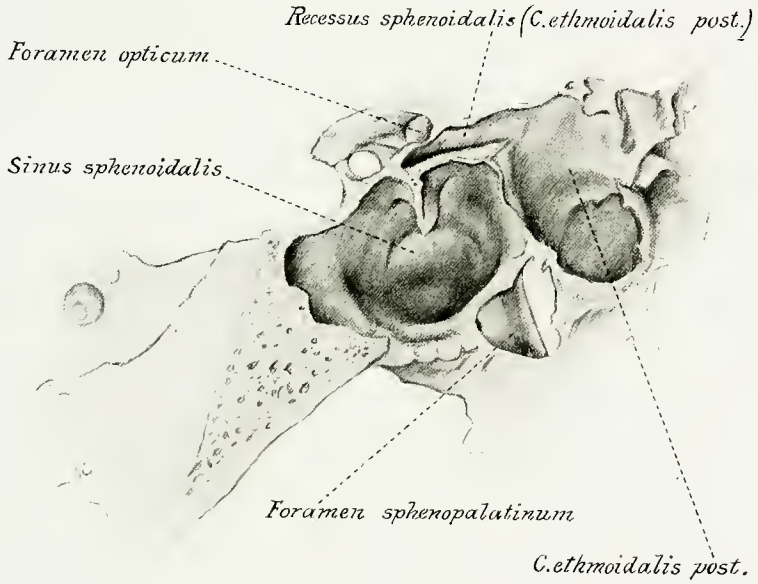

FIG. 155.—A sagittal section through the sphenoidal sinus and a posterior ethmoidal cell. Particularly note the extension of the posterior ethmoidal cell (recessus sphenoidalis) over the sphenoidal sinus into the body of the sphenoid bone. The extension of the ethmoidal cell comes into intimate relationship with the optic foramen and the contained optic nerve.

may stop short of the agger nasi and more or less hollow out the base of the ventral portion of the uncinate process, particularly where the uncinate process and the ethmoidal bulla are confluent. Additional infundibular cells may grow from the ventral and cephalic extremity of the ethmoidal infundibulum, but they are, as a rule, small. It has been suggested (Mosher)[1] that the frontal sinus may be probed with greater ease by passing through the larger agger cell instead of going first lateral to

[1] A Method of Obliterating the Nasofrontal Duct and Catheterizing the Frontal Sinus, The Laryngoscope, Vol. 21, September, 1911.

the middle nasal concha. This would appear correct since not infrequently this cell is of goodly dimension.

The bullar group of the anterior ethmoidal cells arise genetically from the suprabullar, bullar, and infrabullar furrows. Relatively few cells develop from the infrabullar furrow, a slightly larger percentage from the bullar furrow, and almost constantly (95 per cent. of cases) from the suprabullar furrow. These cells variously pneumatize the ethmoidal bulla and cause it to be shell-like. Moreover, it is to these cells that the bulla owes it size and shape. Since the larger percentage of bullar cells develop from the suprabullar recess (see page 30), in the adult most of them have their ostia of communication located between the ethmoidal bulla and the attached border of the middle nasal concha. The number of cells that develop from the suprabullar recess varies from one large cell to four smaller cells. The most ventral of these cells encroach upon cells of the frontal recess, even upon the frontal sinus. Indeed, not infrequently the most ventral bullar cell pneumatizes beyond the ethmoidal field between the two plates of the supraorbital wall, whereof, it is frontal in topography. The most dorsal of the bullar cells very commonly encroach upon certain of the posterior ethmoidal cells; indeed, may topographically be in the position of such cells. Careful dissection, however, shows that they communicate with the suprabullar furrow of the middle meatus and are, therefore, cells of the anterior ethmoidal group. As stated elsewhere, it is the point of drainage, *e.g.*, the location of the ostium or aperture, rather than the topographic position of an ethmoidal cell that determines its classification. The position of a cell is at times very misleading since it may extend far beyond the confines of its allotted field.

The frontal bulla (bulla frontalis) is usually an upward bleb-like swelling or expansion of one or more cells of the anterior ethmoidal group into the floor of the frontal sinus. Multiple frontal bullæ at times mould the floor of the frontal sinus. The ethmoidal bulla (bulla ethmoidalis) may so extend its boundaries by enlargement of its contained cell or cells that it balloons into the dorsal part of the floor of the frontal sinus and forms a conspicuous frontal bulla; moreover, markedly encroaches upon the confines of the frontal sinus. Again the frontal encroaching cells may be outgrowths from the ethmoidal infundibulum (infundibulum ethmoidale), *e.g.*, infundibular cells (see page 213 for their classification). The anterior ethmoidal cells that develop from the frontal recess nearly always encroach upon the frontal sinus or its duct, and at times to such an extent that one or other cell assumes the dignity of a frontal bulla (Figs. 117 and 118).

It must not be forgotten, however, in this connection that the balloon-

like swelling frequently encountered in the floor of one or the other of the frontal sinuses may prove to be a frontal sinus and, indeed, the only frontal sinus of that side (see page 152 and Fig. 85).

The Posterior Ethmoidal Cells (cellulæ ethmoidales posterior).—The posterior ethmoidal cells genetically arise from the superior and first supreme nasal meatuses and in the adult, therefore, communicate with the nasal fossa above the attached border of the middle nasal concha, either with the superior nasal meatus or with the first supreme nasal meatus. It should be recalled that the first supreme nasal meatus is present in approximately 60 per cent. of adult nasal fossæ and that in 75 per cent. of these cases a posterior ethmoidal cell communicates with it; indicating, therefore, that the posterior ethmoidal cell in question arose from the first supreme nasal meatus (see page 23). The superior nasal meatus never fails according to the author's series of specimens to give rise to one or more posterior ethmoidal cells. These cells variously pneumatize and make shell-like the lateral ethmoidal mass above the attached border of the middle nasal concha. Not infrequently these cells extend beyond the confines of the ethmoidal field and form ethmomaxillary, ethmosphenoidal and ethmofrontal cells. Moreover, the posterior and anterior groups of ethmoidal cells overlap each other's fields as regards topography, but not, as stated elsewhere, as regards the drainage of the two groups.

There is no constancy in the number of posterior ethmoidal cells that are differentiated, the author finding them to vary from one to seven. Not infrequently the posterior ethmoidal labyrinth when composed of but one or two cells occupies as much space as when composed of five, six or seven cells. It does, however, mean when few cells are present that they are correspondingly much larger than the average.

Very commonly the posterior ethmoidal labyrinth is, however, not confined to the lateral ethmoidal mass. The extensions of its cells into the ethmoidal appendages (major and minor conchæ or turbinates) will be discussed in subsequent paragraphs under the caption "conchal cells." In the discussion of duplication of the maxillary sinus (page 118) mention was made of the very common extension of a posterior ethmoidal cell into the dorsal and cephalic and medial angle of the body of the maxilla. Such an ethmoidal extension pneumatizes into the body of the maxillary bone at the expense of the maxillary sinus. Moreover, it anatomically simulates a duplication of the maxillary sinus. Careful study, however, indicates its true genesis as a posterior ethmoidal cell and that it nearly always communicates with the superior nasal meatus. This "*ethmomaxillary*" *posterior ethmoidal cell* develops variously, at times occupying a relatively

small portion of the maxilla where the infraorbital and infratemporal surfaces meet, immediately ventral to the pterygopalatine (pterygomaxillary) fossa. At other times the ethmomaxillary cell may assume large proportions, occupying from a fourth to a half of the body of the maxilla. The maxillary sinus is, of course, proportionately reduced in size (Fig. 101). It is, moreover, obvious that an ethmomaxillary cell if of considerable size is, from a clinical viewpoint, more maxillary than ethmoidal despite its origin from the ethmoid bone. The ethmomaxillary cell (or better sinus, if large) has its ostium or aperture located at its most cephalic point, normally in the superior nasal meatus; and, not unlike the ostium of the maxillary sinus, is very disadvantageously located for efficient drainage, *e.g.*, gravity drainage is wholly absent in the usual upright posture of the body. In disease, a goodly sized ethmomaxillary sinus doubtless behaves like the maxillary sinus proper. The operator must, however, remember that in all likelihood a healthy maxillary sinus proper would be opened into in an empyema of the ethmomaxillary sinus unless a rhinoscopic and skiagraphic study preceded the operation.

In the more usual and moderately sized posterior ethmoidal cells the optic nerve at the optic foramen is separated from the most dorsal and superior of the cells by bone from 2 to 5 mm. in thickness. The ethmoid labyrinth being placed in the sagittal plane, the optic nerve as it courses toward the eyeball diverges more and more from the posterior ethmoidal cells as one passes from the optic foramen toward the eyeball. Not infrequently certain of the posterior ethmoidal cells invade the sphenoid bone in the formation of ethmosphenoidal cells (Fig. 141). The latter extend variously dorsalward into the body and lesser wing of the sphenoid bone over the sphenoidal sinus; indeed, may extend sufficiently far to come into very intimate relationships with the optic nerve at the optic foramen and for a considerable distance in front of it. The lamella of bone intervening between the mucous membrane of the ethmosphenoidal cell or sinus and the optic nerve is not infrequently reduced to a tissue-paper delicacy. Indeed, the lamella of bone may be deficient at places so that the optic nerve is directly exposed to the mucous membrane of the ethmosphenoidal cell. The importance of this not infrequent very intimate relation between certain of the posterior ethmoidal cells and the optic nerve must be thought of in connection with blindness of nasal origin.

These sphenoethmoidal cells are at times of such a size that they replace almost entirely the sphenoidal sinuses and, therefore, preclude the sphenoidal sinuses from establishing the usual relationships with the optic nerve. Just as the optic nerve at times courses almost within the

lumen of the sphenoidal sinus (Fig. 140), it may be almost entirely surrounded by an extensively developed posterior ethmoidal cell which has pneumatized into the body and lesser wing of the sphenoid (Fig. 155).

The extension of posterior ethmoidal cells into the frontal bone is extremely commonplace. They usually extend dorsal to the frontal sinus proper for a greater or less distance over the orbit and are, therefore, frequently called ethmoorbital or ethmofrontal cells.

Occasionally the posterior ethmoidal cells so develop and arrange themselves that they form the boundaries of the pterygopalatine (pterygomaxillary) fossa and thereby replace the more usual maxillary sinus boundary in front and the sphenoidal sinus boundary above and behind (see pages 179, 318 and 319). It is, therefore, wholly possible that the sphenopalatine or nasal ganglion of Meckel be at times exposed to the influences of the posterior ethmoidal labyrinth, both in health and disease.

The Conchal Cells (cellulæ conchales).[1]—Not infrequently cells of both the anterior and posterior ethmoidal groups grow into the concha nasalis media, the agger nasi, and the processus uncinatus. It is to this group of cells that the name cellulæ conchales is applied.[2] Such cell extensions may be single or multiple, both unilaterally and bilaterally. It must, however, be stated at the outset that these cells do not differ in any manner, save in their location, from the posterior ethmoidal cells which make shell-like the superior and supreme conchæ, and the anterior ethmoidal cells which pneumatize to a papery delicacy the ethmoidal bulla.

Since the time of Santorini, who apparently was the first anatomist to call attention to the cavity frequently found in the middle nasal concha, many conflicting and erroneous hypotheses have been advanced as to the nature and origin of these spaces. Many of the theories are from the pens of earlier clinicians who removed at operation portions of the walls of such cavities that were changed by pathological processes and attempted to explain the origin of these spaces by a faulty interpretation of the altered tissue removed. The cavities have been variously termed cysts, abscesses, osseous cysts, exostoses, neoplasms, ectasias of the ethmoid bone, aberrated ethmoidal cells, and when large and occurring in the ventral portion of the concha media, as conchæ bullosæ.

[1] H. A. Lothrop, Annals of Surgery, Vol. 38, 1903.
George E. Shambaugh, Trans. Amer. Laryngol. Assoc., 1907.
J. Parsons Schaeffer, Anat. Rec., 1910.
Glasmacher, Berliner Klin. Wochenschr., 1884.
Depuytren, Clinique Paris, Vol. 11, 1830.

[2] J. Parsons Schaeffer: On the Genesis of Air Cells in the Conchæ Nasales, Anat. Record, Vol. 4, No. 4, 1910.

In order to better understand these cells and to see that they are nothing other than ethmoidal cells, it is essential that the origin of the ethmoidal labyrinth be kept in mind. The location of these cells appears less abnormal when one recalls that the ethmoidal conchæ and the processus uncinatus are merely appendages of the lateral ethmoidal masses. There is no reason, therefore, why ethmoidal cells should not at times in the formation of the ethmoidal labyrinth grow into the appendages just as they grow into the lateral ethmoidal masses proper.

According to the author's reconstructions[1] of the lateral wall of the nasal cavity of different aged fetuses, the primitive ethmoturbinal fold, with its subsequent modifications, is not concerned only in producing the

FIG. 156. FIG. 157. FIG. 158.

FIGS. 156, 157 and 158.—Frontal sections of the left nasal fossa in the region of the bulla ethmoidalis from a term fetus (series *D*, slides 5, 6 and 7).

Note the development of ethmoidal cells in the concha media and the bulla ethmoidalis. None of the sections is far enough ventrad to pass through the ostium of the maxillary sinus.

C = cellulæ ethmoidales; *M.n.m.* = meatus nasi medius; *M.n.i.* = meatus nasi inferior; *C.n.med.* = concha nasalis media; *B. eth.* = bulla ethmoidalis; *Inf. eth.* = infundibulum ethmoidale; *Proc. unc.* = processus uncinatus; *S. max.* = sinus maxillaris; *F. cr. ant.* = fossa cranii anterior.

ethmoidal conchæ and the intervening furrows (meatuses), but also with the structures operculated by the concha nasalis media, *e.g.*, the processus uncinatus, the bulla ethmoidalis, the hiatus semilunaris, and the infundibulum ethmoidale. These modifications are all intimately related to the rudiments of the paranasal sinuses.

The posterior group of ethmoidal cells are primarily constricted from or are direct extensions of the furrows separating the primitive ethmoidal conchæ, and the anterior group of ethmoidal cells develop from preformed

[1] Loc. cit.

accessory furrows of the middle meatus; therefore, are in relation to the furrows and folds found in this location. In this connection it is an interesting fact to note that the ostia of conchal cells invariably communicate directly or indirectly with the points from which ethmoidal cells normally develop. Moreover, a study of a series of specimens proves that conchal cells are either parts of other ethmoidal cells which determine their nasal connection or they communicate (*a*) directly with the superior

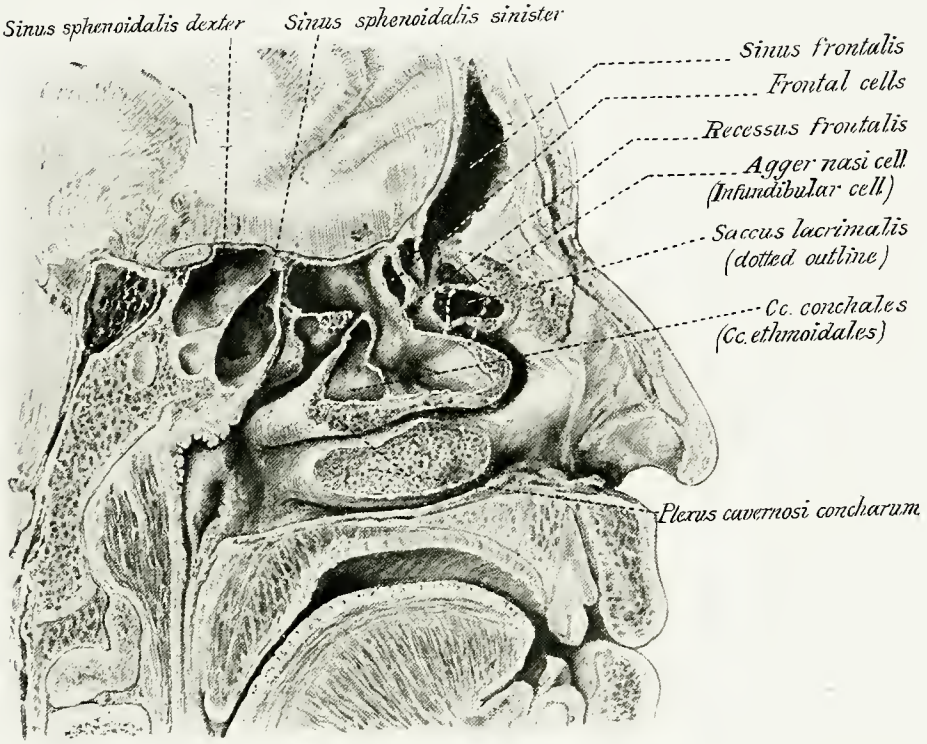

FIG. 159.—The lateral nasal wall with the paranasal sinuses exposed, the maxillary sinus excepted. Especially note the extension of posterior ethmoidal cells (Cc. conchales) into the middle nasal concha. Moreover, note how the cell in the agger nasi overlays the lacrimal sac. In the endonasal approach of the lacrimal sac and nasolacrimal duct it is this cell that is opened into first. The condition is common. The erectile character of the mucous membrane is marked over the inferior and middle conchæ.

meatus, (*b*) with the infundibulum ethmoidale, or (*c*) directly with the ventral end of the middle meatus. The ostia in the latter case are on the lateral surface of the concha nasalis media.

Although the rudiments of the ethmoidal cells are primarily constrictions or extensions from the nasal fossæ, the further extension and development of these cells depend upon the simultaneous processes of growth (of the sacs) and resorption (of surrounding tissue). In this manner the

cells extend farther and farther into the lateral masses of the ethmoid bone as age advances, and in the adult are completed by the articulation of the ethmoid bone with the frontal, lacrimal, sphenoid, maxillary, and palate bones. These developmental processes are not uniform and, doubtless, are carried farther in some cases than in others, hence the extension of ethmoidal cells not only farther into the lateral mass of the ethmoid bone, but also into its appendages, such as the ethmoidal conchæ, the processus uncinatus, etc.

A reference to Figs. 159 and 160 shows the extension of the inferior ethmoidal groove (superior nasal meatus) not only into the lateral ethmoidal mass, but also into the concha media, thus forming conchal cells

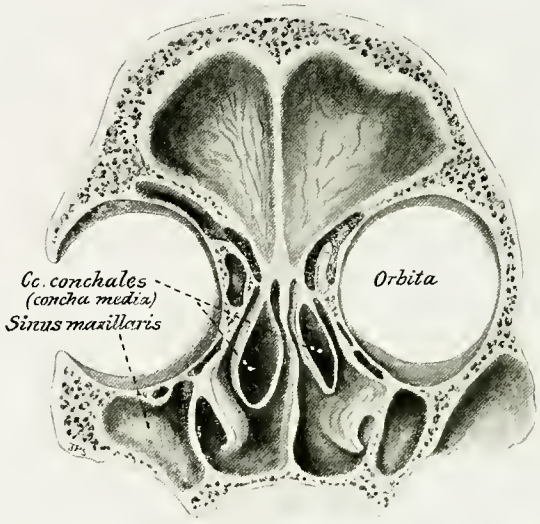

FIG. 160.—A frontal section through the skull of an adult. Note the supraorbital extensions of the frontal sinuses and the large ethmoidal cells in the middle nasal conchæ.

which are merely parts of the more usual posterior lateral mass cells. At first thought it may seem difficult to account for the conchal cells having their ostia opening inferior to the attachment of the concha media, either into the middle meatus or the ethmoidal infundibulum. However, when one recalls the great modifications of this portion of the middle meatus overhung by the concha media, incident to the formation of the structures found there, and that the anterior group of ethmoidal cells have their origin in this position, it is not difficult to see why some of these cells extend not only into the lateral mass of the ethmoid bone, but also into the processus uncinatus, the concha media, and the agger nasi.

In Fig. 158 is represented a photograph of a specimen in which a conchal cell is already present in the concha nasalis media of a fetus at

term. Of course, most conchal cells must necessarily appear comparatively late in the formation of the ethmoidal labyrinth, since the positions they occupy with reference to the ethmoidal cell rudiments are relatively far removed. The extensions into the conchæ, etc., would, therefore, in most cases be delayed probably until puberty, or even later, when the ethmoidal labyrinth reaches its full development. Knight's statement:

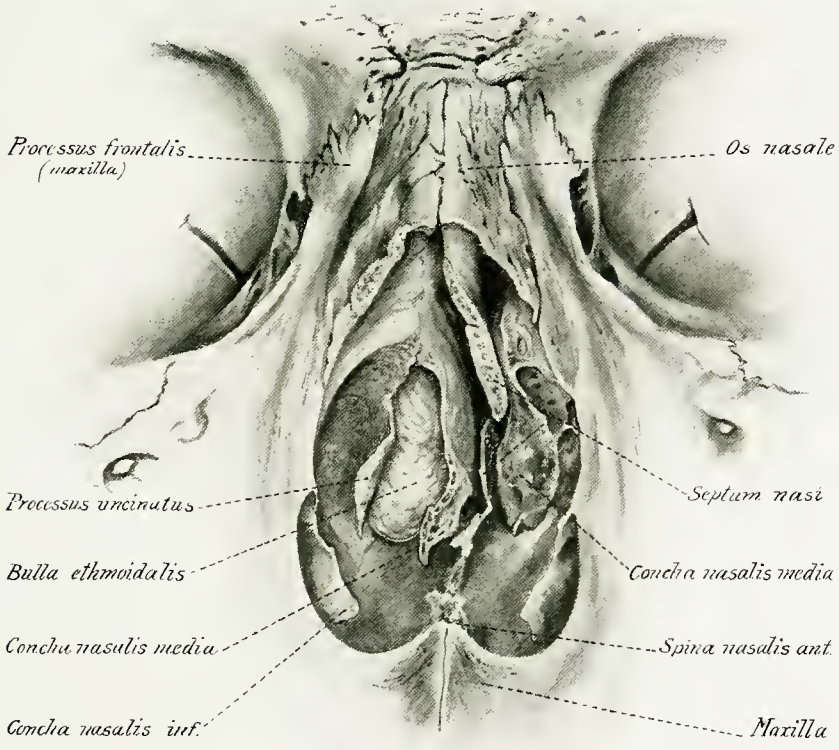

FIG. 161.—An enormously developed bulla ethmoidalis as seen through the osseous pyriform nasal aperture. Note that the uncinate process is crowded caudo-laterally and the concha nasalis media thinned out and crowded against the septum nasi. Obviously the enlarged bulla was the prime factor in the deviation of the septum.

"Children seem to be exempt. None of the patients was under 20 years of age," is misleading. If late fetuses show conchal cells (Fig. 158) surely children are not exempt.

Extensions of ethmoidal cells (infundibular) into the agger nasi are not uncommon (Figs. 153 and 159). There is no reason why cells in this location could not extend farther and finally reach and occupy the ventral

end of the concha inferior. Such an extension would explain Schaeffer's cell of the ventral end of the inferior nasal concha. The writer finds that cells in the latter position are extremely rare.

Careful examination of conchal cells shows that they do not differ in any manner from the ethmoidal cells of the lateral masses. This is true macroscopically and microscopically. The mucous membrane lining conchal cells is extremely thin, but corresponds in its general structure to that lining the other ethmoidal cells, unless changed by a pathological process. It must be remembered that conchal cells, like any of the ethmoidal cells or of the paranasal sinuses, may become the seat of an empyema or a mucocele, and enlarge, because the ostia of these cells are invariably placed at the highest points of the cavity and very disadvantageously placed as drainage openings, a fact easily understood when their development is considered. The existence of air cells in the conchæ, etc., is certainly not the result of an empyema or rarefying osteitis, but because these cells are normally found in these positions they may become the seat of pathological conditions just as do other cells of the ethmoidal labyrinth.

Sex does not have any bearing on the development of conchal cells, and they are about equally divided as to whether the ostia open cephalic or caudal to the attached border of the concha nasalis media.

Santorini[1] thought conchal cells (referring to the concha media) quite common, but says he should not venture to say that the condition was constant. He apparently regarded these cells much more frequent than they really are. According to Reardon, Zuckerkandl observed them 8 times in 172 skulls. Knight says that Zuckerkandl "found them 36 times in 200 postmortem examinations." Lothrop found them in 9 per cent. of all cases. The author in an examination of over 200 adult nasal fossæ found conchal cells in approximately 12 per cent. of the specimens.

The Middle Conchal Sinus.—The so-called middle conchal sinus (a pseudo paranasal sinus), formed by the lateral and superior curling of the free border of the concha media, is not homologous with nor analogous to the conchal cells. Nevertheless, in some cases it may retain fluid in its hammock-like fold; indeed, may become the seat of an empyema or a mucocele. The majority of middle conchæ do not, however, show the sinus and when present it is, as a rule, of minor importance (Fig. 162).

Concluding Considerations.—As may be inferred from the foregoing paragraphs, it is difficult in skiagrams to distinguish the anterior ethmoidal

[1] Dominici Joannes Santorini: Observationes Anatomicæ, pp. 88–89, 1739.

cells from the frontal sinus in the early postnatal period. This is, of course, due to the genetic and early intimate topographic relationships between the most ventral of the ethmoidal cells and the frontal sinus (Figs. 36 and 37). The fact that the skiagram fails to differentiate the frontal sinus at this early period is of little importance clinically since both the frontal sinus and the anterior ethmoidal cells in diseased states are doubtless conjointly involved. The nature of the anatomy of the region

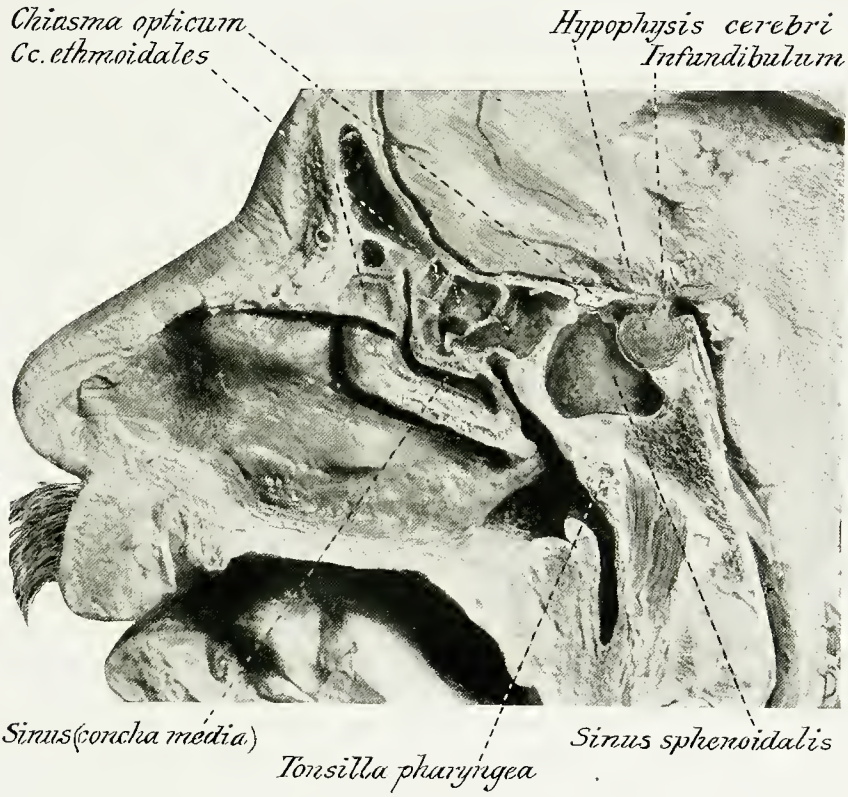

FIG. 162.—A sagittal section through the ethmoidal labyrinth, sphenoidal sinus, frontal sinus and the hypophysis cerebri. Especially note the pseudo paranasal sinus (sinus conchæ mediæ) in the middle concha (see text, page 226).

(early childhood period of the frontal recess and its derivatives) is such that the simultaneous involvement of all cellular outgrowths is certain. The skiagram does reveal the frontal recess with its paranasal derivatives and treatment must be directed to the region rather than to an individual cell or sinus at this early time. Indeed, it may not be until the second year of infancy that one is certain which part of the frontal recess or which ethmoidal cell is really destined to become topographically the frontal

sinus. Despite this, it must, however, be recalled that the rudiment of the frontal sinus is far advanced long before this period (see embryology, Chapter I). Of course, after the second year the frontal sinus rapidly assumes larger dimensions and begins to pneumatize well beyond the confines of the frontal recess, so that it is not infrequently clearly indicated as such on X-ray pictures.

The ethmoidal cells in children often appear indistinct and blurred in skiagrams. Electrical transillumination appears to be utterly unreliable. Rhinoscopic examination of the ethmoidal field is practised with

FIG. 163.—The bony orbit, the medial wall of which bears intimate relationships to the paranasal sinuses.

1 = frontal; 2 = nasal; 3 and 11 = maxilla; 4 = lacrimal; 5 = ethmoid; 6, 8 and 9 = sphenoid; 7 = palate; 10 = zygomatic.

great difficulty during the early childhood period owing to the limited size of the nasal fossæ, and Haike is convinced that despite its limitations the skiagram offers the only reliable diagnosis of ethmoidal affections in children.

Despite the fact that the nasal fossæ and its meatuses are relatively narrow in young children, making the endonasal approach and exposure of the ethmoidal labyrinth difficult, both the anterior and posterior groups of ethmoidal cells are of goodly size even during the first years of postnatal life and rapidly assume larger dimensions as age advances (see Table L, page 211). While the anatomy of the early nasal cavity is such that

endonasal treatment of the ethmoidal cells must be limited in large measure to irrigation, it cannot be gainsaid that the location and relatively advanced state of development of the ethmoidal labyrinth justify radical operations when the endonasal methods fail. In this connection it is, of course, necessary to recall the relations of the ethmoidal labyrinth other than its nasal exposure. The ethmoidal cells have been operated

FIG. 164.—A dissection of the paranasal sinuses. The lining mucous membranes are represented. The cadaver was first formalized, then the osseous boundaries were removed piecemeal.

upon in children by way of the nasal cavity, the frontal sinus, the maxillary sinus, and the medial side of the orbit (resection of the orbital plate, lamina papyracea). The early intimate anatomic relationships between the ethmoidal cells and the orbital cavity must always be recalled in ethmoidal affections. Radical operations have been performed on the ethmoidal cells in children as young as 30 months of age[1] and more fre-

[1] E. Myer, Berliner Klin. Wochenschr., 1905.

quently as age advances and both the ethmoidal labyrinth and nasal fossa assume larger proportions.

Transillumination is not to be depended upon as a means of outlining the normal and fully developed ethmoidal labyrinth, and is utterly unreliable in ethmoidal suppuration in the opinion of many investigators.

FIG. 165.—Frontal skiagram of a dryed skull of an adult. Note the paranasal sinuses. The preparations shown in Figs. 165, 166, and 166*A* were *x*-rayed by Prof. Manges.

Roentgenography, on the other hand, is of distinct value in the study of the normal ethmoidal labyrinth, despite its limitations. Especially are skiagrams of value in the delineation of the anterior group of ethmoidal cells in their relationships with the floor of the frontal sinus. Moreover,

such pictures are desirable when the endonasal approach of the frontal sinus is attempted.

Fortunately in the later childhood and adult periods the nasal fossa and meatuses have assumed larger proportions, making the direct endonasal examination of the ethmoidal field possible and feasible. Indeed, some clinicians claim that the presence of pus in the ethmoidal cells can better be determined by direct examination than by roentgenography.

FIG. 166.—Profile skiagram of a dryed skull.

However, the skiagram is of real value in the detection of suppuration and purulent collections. Turner and Porter have been unable in frontal X-ray exposures to satisfy themselves "of the possibility of differentiating between disease of the anterior and posterior groups of cells." Moreover, it is well known that profile skiagrams not only picture the ethmoidal cells of that side, but also the cells of the opposite side. This appears to interfere with the recognition with certainty of unilateral affections. The experienced roentgenologist, however, not infrequently correctly

interprets the ethmoidal field in skiagrams. It is obviously not a work for the novice.

To obviate the overlapping of ethmoidal cells as occurs in frontal skiagrams and the projection of the opposite ethmoidal labyrinth over the ethmoidal field under investigation as occurs in profile skiagrams, it would appear that the methods of Pfahler and Pfeiffer should be of

FIG. 166A.—Profile skiagram of a sectioned head of an adult negro. The paranasal sinnses are filled with Wood's metal and are indicated by the deep black outlines. The nasolacrimal duct is shown coursing above and medial to the forepart of the maxillary sinus. The horizontal white lines indicate the planes of section.

distinct advantage. Both of the methods take the skiagram through the vertical diameter of the head and picture both the complete ventrodorsal and transverse diameters of the bilateral ethmoidal labyrinth with much less overlapping and superimposing of cells. The anatomy of the ethmoidal labyrinth is, of course, such in very many cases that some over-

lapping of cells in X-ray pictures is inevitable regardless of the exposure.

The anatomic position of the ethmoidal field is of great importance in diseased states of its honeycomb-like structure. Infection may readily extend into the orbit, giving rise to an orbital cellulitis. At best the orbital plate or lamina papyracea intervening is of extreme delicacy and not infrequently of a fenestrated nature due to congenital dehiscences. The very intimate relationship between certain of the anterior group of ethmoidal cells and the lacrimal fossa and sac lead to frequent secondary involvement of the lacrimal sac (dacryocystitis) in ethmoidal infection (see page 253). The cranial cavity may be involved, the ethmoidal infection extending by way of the ethmoidal veins. The very intimately related ophthalmic vein may carry infection into the dural cavernous sinus. Occasionally, especially in children, the small vein which traverses the foramen cæcum infects the superior sagittal or longitudinal dural sinus.

The location of many of the anterior group of ethmoidal cells is such that they drain directly or indirectly into the infundibulum ethmoidale and from there through the ostium maxillare into the maxillary sinus. The latter may, therefore, become a cesspool for infectious materials from certain of the cells of the ethmoidal labyrinth (see also frontal sinus, page 172).

The very common extensions of the ethmoidal cells into the middle nasal concha, the uncinate process, the agger nasi, etc., must not be forgotten in dealing with the bleb-like enlargements of these structures (page 225). Moreover, the extension of certain ethmoidal cells into neighboring bones is of distinct clinical importance, especially those that simulate maxillary and sphenoidal sinuses (see pages 219, 220). It is equally important clinically to recall that many of the ethmoidal cells have no gravity drainage in the more usual postures of the body. In this regard such cells are not unlike the maxillary and sphenoidal sinuses. Some of the ethmoidal cells, however, have dependent or gravity drainage and are not unlike the frontal sinus in this respect.

VII—THE NASOLACRIMAL PASSAGEWAYS

CHAPTER VII

THE NASOLACRIMAL PASSAGEWAYS

The *lacrimal sac* (saccus lacrimalis) and the *nasolacrimal duct* (ductus nasolacrimalis) are very intimately related to the lateral wall of the nasal fossa and to certain of the paranasal (accessory) sinuses. The *lacrimal ducts* (ductus lacrimales, lacrimal canaliculi) are not intimately related to the parts in question save as they near and connect up with the membranous lacrimal sac. Moreover, the nasal fossa serves as a drainage chamber for the lacrimal apparatus, receiving the lacrimæ or tears in the inferior meatus. The intimate relationship between the nasolacrimal duct and the nasal fossa is taken advantage of surgically, intranasal dacryocystotomy (dacryocystorhinostomy) being frequently practised in stenosis of the nasolacrimal duct. It is, therefore, deemed apropos and essential in this connection to analyze the regional and topographic anatomy of the lacrimal ducts, the lacrimal sac and the nasolacrimal duct, with especial reference to the nasal fossa and the related paranasal sinuses and to refer to other developmental and anatomical features that are of importance here.

Genetic and Developmental Anatomy.—In order that the variations in the topography and anatomy of the fully established nasolacrimal passageways may be properly interpreted, it is necessary that one recalls the fundamental developmental stages in the formation of the channels. As is well known, at one stage of the human embryo there extends a fissure or furrow, the *naso-optic fissure*, from the eye to the nasal pit. This fissure is bounded superiorly by the embryonic lateral nasal process and inferiorly by the embryonic maxillary process (see page 4). The naso-optic fissure gradually disappears normally by a growth and coalescence of the structures bordering it. The coalescence or fusion of the lateral nasal and maxillary processes takes place from within outward, thereby "outfolding" the intervening naso-optic fissure (Fig. 167). The strand of thickened epithelium along the floor of the now rudimentary naso-optic fissure undergoes further proliferation and suffers absolute and complete detachment from its surface connections and becomes entirely surrounded by the subjacent mesenchymal tissue into which the detached epithelial cord sinks (Fig. 169). The related and surrounding mesenchyme is des-

tined in part to form the maxilla, the inferior conchal or turbinated bone and the lacrimal bone. The surface-detached and mesenchymal-surrounded solid epithelial cord is the forebear or anlage of the naso-lacrimal passages. The original solid cord grows cephalically, giving rise

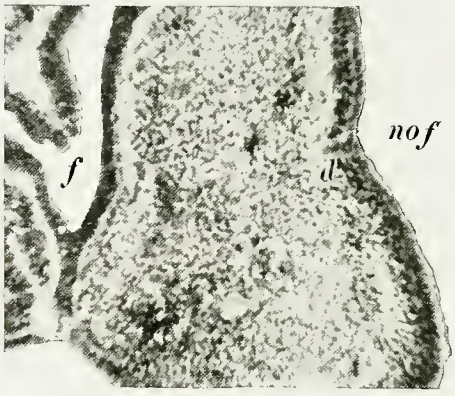

FIG. 167.—Photomicrograph of a frontal section of the head of a human embryo aged 35 days. Note in the region of the naso-optic furrow (*nof*) the nipple-like thickening (*d*) of the surface ectoderm in the formation of the rudiment of the nasolacrimal passageways. ×7.

normally to the cupola of the lacrimal sac and by secondary outgrowths to the two lacrimal ducts. Moreover, it grows nasalward and establishes connections with the epithelium of the inferior nasal meatus. The solid cord and its secondary outgrowths or sprouts, by a rearrangement of their

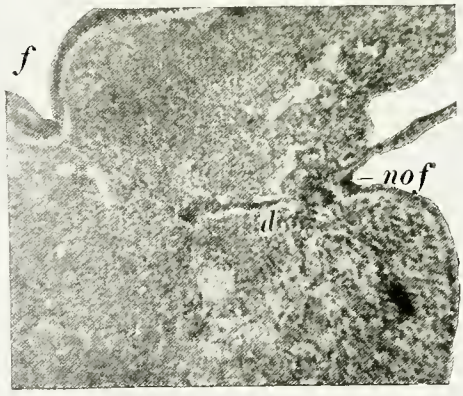

FIG. 168.—Photomicrograph of a frontal section of the head of a human embryo aged 36 days. Note the growth of the rudiment of the nasolacrimal passageways (*d*) and compare with Fig. 167. *Nof* = remains of naso-optic furrow. ×7.

cellular elements, become hollow and form the duct connections between the conjunctival culdesac and the inferior meatus of the nasal fossa. Ossification of the surrounding mesenchyme takes place in the formation of the maxilla, the inferior turbinated and the lacrimal bones, so that ulti-

mately the membranous nasolacrimal duct and the lower portion of the membranous lacrimal sac become encased in an osseous canal (canalis nasolacrimalis) formed by the maxilla and the inferior turbinated and the lacrimal bones. The lacrimal ducts and the greater portion of the lacrimal sac do not become encased by bone, the former coursing within the soft tissues of the eyelids and the latter resting in the shallow lacrimal fossa (Fig. 173).

The nasolacrimal passageways, at first solid epithelial cords, ultimately become canalized in an irregular manner. The canalization is in reality nothing other than a rearrangement of the epithelial cells around a centrally placed lumen rather than a necrobiosis of central cells. The ocular end of the solid nasolacrimal duct is the first to establish a lumen. The horizontal portions of the lacrimal ducts (canaliculi) establish lumina be-

FIG. 169.—Photomicrograph of a frontal section of the head of a human embryo aged 43 days. Note the complete detachment of the rudimentary nasolacrimal passageways (*d*) from the surface ectoderm. The "passageways" are solid epithelial cords and entirely surrounded by mesenchymal tissue at this time. ×7.

fore the vertical portions (Fig. 170). The point of coalescence between the nasal end of the solid nasolacrimal duct and the mucous membrane of the inferior nasal meatus is the last point in the entire duct system to become patent. In most instances, canalization here is deferred until the end of fetal life. Indeed, the author has made many observations in which a membranous barrier between the nasolacrimal duct and the inferior meatus existed during the first weeks of infancy (Fig. 171).

One of the striking features of the nasolacrimal duct at birth is its relatively large diameter and extremely irregular walls. The latter condition gradually disappears to a large degree; some of the recesses, however, developing into diverticula, others remaining as mucosal shelves and so-called valves. The nasolacrimal duct at birth averages about 2 mm. in

diameter. By the third year the diameter has increased to 3 mm. or over, extremes being observed from 1.5 mm. to 6 mm. The latter diameter is, however, very unusual.

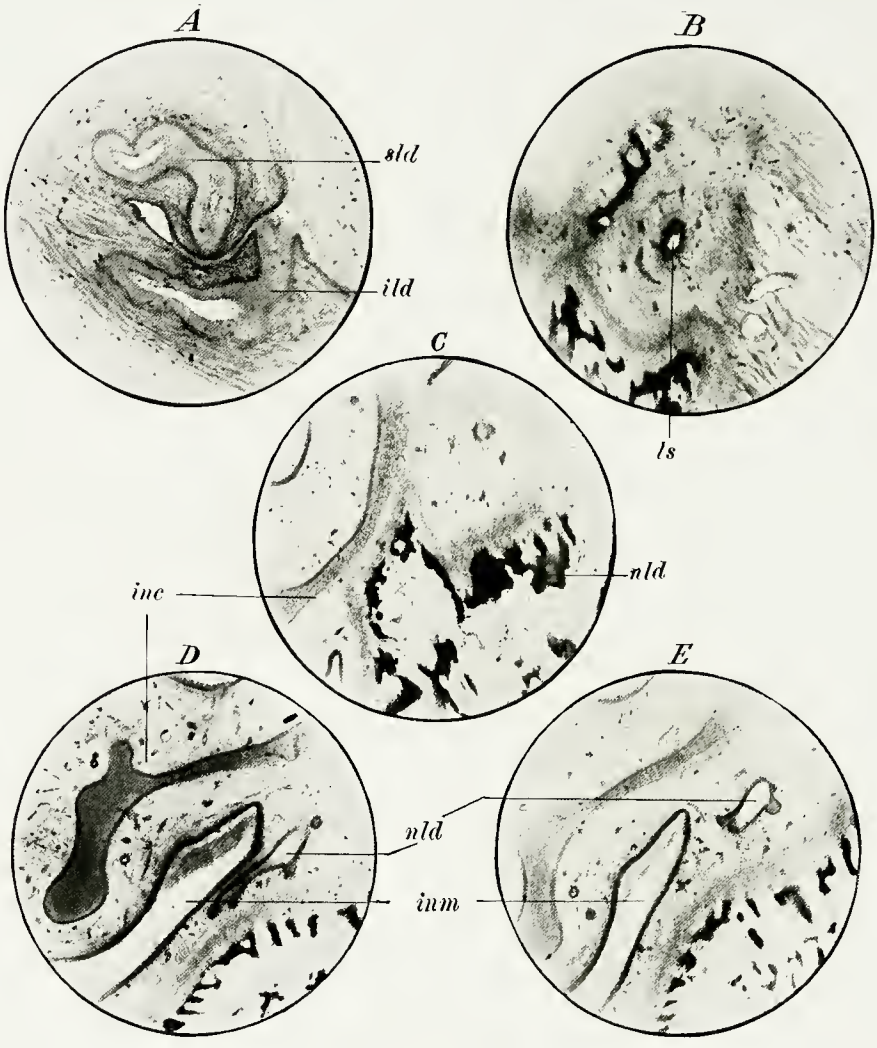

FIG. 170.—Photomicrographs of frontal sections through the nasolacrimal passageways of a human embryo aged 128 days. Note the solid portions of the lacrimal ducts in Fig. *A*. In Fig. *B*, we have a patent section (*ls*) of the ocular end of the nasolacrimal duct and in Fig. *C*, a section of the mid-portion of the nasolacrimal duct still solid (*nld*). Note the well established lumen (*nld*) at the nasal end of the nasolacrimal duct in Figs. *D* and *E*. Note how extensive the contact point between the nasolacrimal duct and the inferior nasal meatus will be (Fig. *D*).

Sld = superior lacrimal duct; *ild* = inferior lacrimal duct; *ls* = lacrimal sac; *nld* = nasolacrimal duct; *inc* = inferior nasal concha; *inm* = inferior nasal meatus. × 19. (*After J. P. S.*)

The lacrimal sac and the nasolacrimal duct are relatively fixed from the onset as far as position is concerned. The paranasal (accessory) sinuses are, therefore, not as intimately related to the nasolacrimal pas-

sageways as later when the sinuses assume larger dimensions. Despite the general truth of the foregoing, the maxillary sinus and the nasolacrimal duct bear important and fairly close anatomic relationships even before birth. At birth the nasolacrimal duct lies on the average but 2 mm.

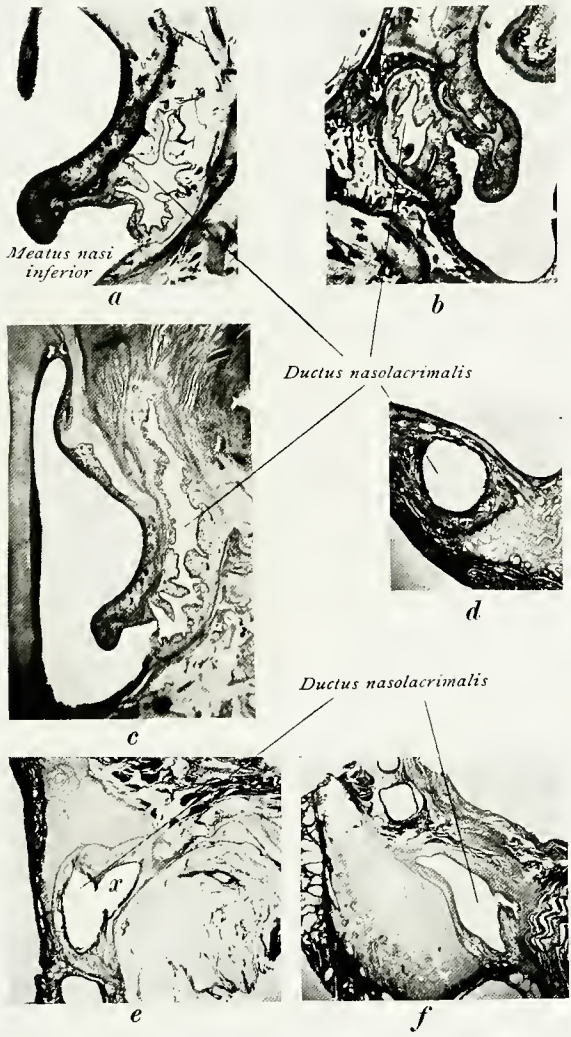

FIG. 171.—Photomicrographs of sections through the nasolacrimal duct. *A*, from a child at term. Note that the barrier (lacrimonasal membrane) between the nasolacrimal duct and the inferior nasal meatus is still intact. ×3.4. *B*, from a 7-month fetus, the lacrimonasal membrane intact. ×6. *C*, from a term child, the lacrimonasal membrane markedly thinned out but unruptured. Particularly note the irregularity of the nasolacrimal duct. *D*, from an adult, aged 60 years. *E*, from an adult, aged 65 years. Note the diverticulum (*X*). ×2.6. *F*, from an adult, aged 70 years. In the region of the ostium of the common lacrimal duct.

directly in front of, or from 1.5 mm. to 2 mm. medial to the ventral end of the maxillary sinus. By the eighteenth month the distance intervening

between the maxillary sinus and the nasolacrimal duct is reduced for a limited segment of the duct to an intimacy not unlike in the adult. Of course, only later, when the infraorbital recess assumes goodly proportions, is the nasolacrimal duct exposed to the surface of the maxillary sinus for a considerable distance.

Of the ethmoidal cells, those developing from the frontal recess of the middle nasal meatus are nearest the lacrimal sac at birth. However, the anatomic relationship is not intimate at this time. Indeed, in a child aged from 18 to 24 months from 5 to 7 mm. usually intervene between the lacrimal sac and the nearest ethmoidal cell (Fig. 151). Rarely a more precocious ethmoidal cell establishes very intimate anatomic relations with the sac at an earlier period of extrauterine life.

By the sixth year the maxillary sinus establishes fairly intimate relationships with the upper portion of the nasolacrimal duct, and the frontal ethmoidal cells have pneumatized the region formerly existing between the lacrimal sac and the frontal recess. Infundibular cells likewise not infrequently early seek lacrimal sac relations. Indeed, the rudimentary frontal sinus (either frontal recess or frontal ethmoidal cell, see page 143) must be thought of in the early relationships of the lacrimal sac.

After the eleventh year the anatomic relationships between the paranasal sinuses and the nasolacrimal passageways are essentially those of the adult (Fig. 153).

Variations and Anomalies.—The variations and anomalies in the nasolacrimal passageways as encountered in postfetal life are readily accounted for by the potentialities of development of the anlage of the duct system. Double and triple lacrimal puncta and lacrimal ducts have been observed by the author. Indeed, Majewski found a case of quadruple puncta. Should the cephalic end of the solid epithelial cord give rise to more than two lacrimal sprouts, the usual number, either the upper or the lower eyelid or both might have multiple lacrimal ducts and puncta. Some of the multiple outgrowths fail, however, at times to reach the free border of the eyelid. Moreover, should one or the other of the two usual lacrimal sprouts fail to reach the free border of the eyelid there would, of course, be an absent lacrimal duct and papilla; or should, perchance, the solid lacrimal sprout after reaching the free border of the eyelid fail to become canalized at that point, a lacrimal papilla with an absent lacrimal punctum would result. It does not necessarily follow that multiple puncta mean a corresponding number of lacrimal ducts; an extensive coalescence of a single lacrimal duct with the free border of the eyelid

may establish multiple ostia or puncta. Again, a lacrimal punctum may be represented by a slit-like furrow along the edge of the eyelid.

Congenital fistula of the lacrimal sac is occasionally encountered as a unilateral or bilateral defect. It usually means an arrested development in the obliteration of the optical end of the naso-optic furrow. At times it would seem that the defect is due to an attenuation of a diverticulum of the lacrimal sac.

Auxiliary lateral buddings of the solid or uncanalized nasolacrimal duct are very common at one stage of the human embryo (Fig. 172). Apparently, many of these suffer early absorption. However, a study

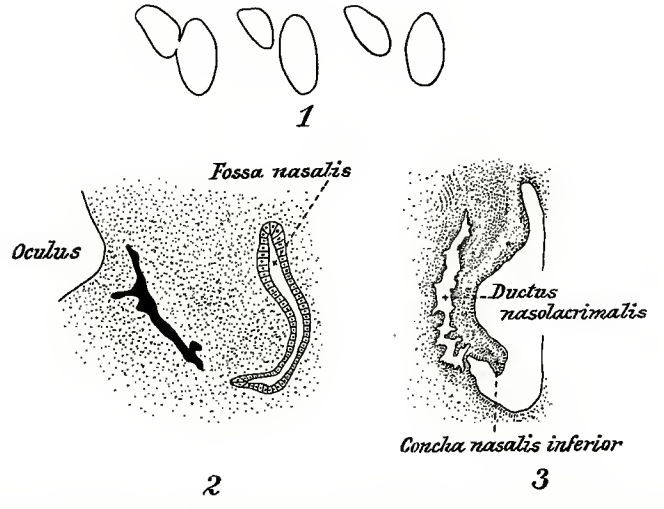

FIG. 172.—In No. 1 are shown outlines of the lumen of the ductus nasolacrimalis at various levels. What appears to be two ductus nasolacrimales lying side by side at one level turns out to be the main duct and a diverticulum from it. From an adult. (*After J. P. S.*)

In No. 2 is illustrated a frontal section through the nasal fossa of a forty-day human embryo. The advanced rudiment of the nasolacrimal passageways is indicated in solid black. Note the complete isolation from the surface and the lacrimal ducts sprouting from the main cord of cells. Lateral auxiliary buds, the rudiments of diverticula, are shown protruding from the main cord of cells. (*After J. P. S.*)

In No. 3 is shown the irregular canalization of the ductus nasolacrimalis. From a child aged one day. (*After J. P. S.*)

of much embryologic and adult material has convinced the author that the very common diverticula of the adult nasolacrimal duct have their origin in these embryonic lateral buddings. As the main duct becomes canalized the process is carried into the auxiliary buds in the formation of diverticula. Indeed, the case described by Geddes[1] in which the nasolacrimal duct communicated with the middle nasal meatus can be explained by such a lateral bud. These diverticula always communicate

[1] An Abnormal Nasal Duct, Anatom. Anz., Bd. 37, No. 1, 1910.

with the main nasolacrimal duct and are lined by an epithelium not unlike that of the main duct (see page 250).[1]

The connections of the uncanalized nasolacrimal duct with the epithelium of the inferior nasal meatus occurs at various levels. At times the coalescence takes place at the highest point or cupola of the inferior nasal meatus. Again, it may occur at any point on the lateral wall of the inferior meatus in the plane of the duct. In the canalization of the field of union between the nasolacrimal duct and the inferior nasal meatus from one to three ostia are established. The single ostium is, of course, the more usual. The attenuation and rupture of the membranous septum, composed of two layers of abutting epithelium with a limited amount of intervening connective tissue, located between the lumen of the nasolacrimal duct and the inferior nasal meatus, is not unlike the rupture of the bucconasal membrane in the establishment of the connection between the primitive nasal fossa and the primitive buccal cavity. Should the membranous barrier between the inferior nasal meatus and the nasolacrimal duct fail of canalization or rupture, atresia of the nasolacrimal duct would, of course, result. The author has encountered atresias in many newborn babies and a few in children that died during the first year of infancy.[2] Doubtless the atresia in the newborn of the nasolacrimal duct due to a persistent *lacrimonasal membrane* is in many instances short-lived—the already thin membrane soon suffering "rupture." Occasionally, however, surgical intervention is necessary (Fig. 172).

The Lacrimal Fossa and the Nasolacrimal Canal.—Before considering the membranous lacrimal ducts and sac and the nasolacrimal duct it is well that one has a clear conception of the osseous relations. The fossa of the lacrimal sac (fossa sacci lacrimalis) is an oblong rounded depression or sulcus located on the ventromedial aspect of the orbit, the frontal process of the maxilla and the lacrimal bone participating more or less equally in its formation. The fossa is limited dorsally by the prominent posterior lacrimal crista (crista lacrimalis posterior) and ventrally by the anterior lacrimal crista (crista lacrimalis anterior), the former a crest on the lacrimal bone and the latter a crest on the frontal process of the maxilla. Cranialward the lacrimal fossa becomes shallower and shallower, ultimately losing its identity at the fronto-lacrimo-maxillary suture line,

[1] J. Parsons Schaeffer: Nasolacrimal Duct Diverticula and Their Genetic Significance, The Anat. Rec., Vol. 9, 1915.

[2] For a more detailed account of the embryology and development of the nasolacrimal passageways in man, the reader is referred to a previous study with an appended bibliography. J. Parsons Schaeffer: The Genesis and Development of the Nasolacrimal Passages in Man, Amer. Jour. Anat., Vol. 13, 1912.

while nasalward the fossa is directly confluent with the osseous nasolacrimal canal (Fig. 145).

The osseous nasolacrimal canal, the direct continuation of the lacrimal sulcus or fossa, is formed by the maxilla, the lacrimal bone and the inferior nasal concha or turbinated bone, the maxilla by its frontal process and body contributing the greater portion of the boundaries. Rarely the

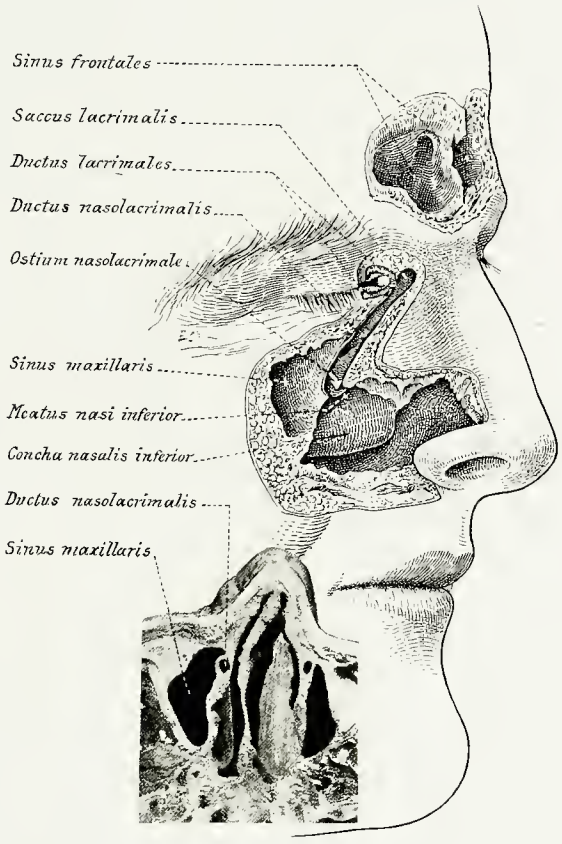

FIG. 173.—A dissection showing the nasolacrimal passageways and the relations of the nasolacrimal duct to the maxillary sinus and the inferior nasal meatus. The inset is a transection of the nasal fossæ, the maxillary sinuses, and the nasolacrimal ducts.

lacrimal bone fails to participate in the formation of the osseous nasolacrimal canal, being replaced by an extension of the frontal bone or the maxilla. The canal terminates immediately below the attached border of the inferior nasal concha on the lateral wall and cupola of the inferior nasal meatus in a wide-mouthed ostium. The length of the osseous nasolacrimal canal does not necessarily conform to the enclosed mem-

branous nasolacrimal duct, which is frequently longer (vide infra). The osseous canal proper varies in length from 10 to 20 mm. and the lacrimal sulcus or fossa from 10 to 14 mm., making a total length of the osseous channels from 20 to 34 mm. The diameter of the osseous canal measures from 4 to 7 mm.; however, is seldom uniform throughout.

The *plane of direction* of the osseous nasolacrimal canal must obviously conform to the type of the facial skeleton. Moreover, the breadth of the bridge of the nose, the degree of expansion of the pyriform aperture, and the width of the inferior nasal meatus are extremely variable and necessarily influence the course of the nasolacrimal canal and its contained membranous duct. In a general way one may say that the direction of

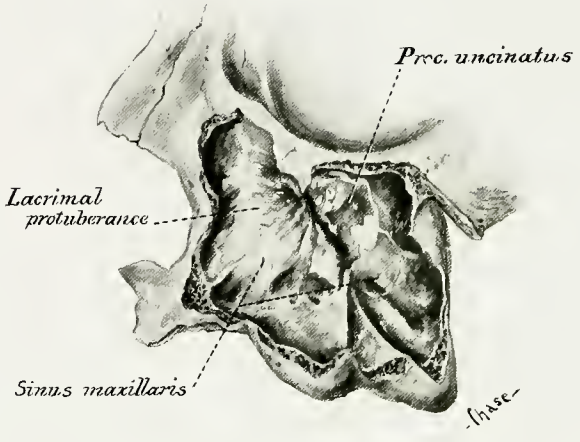

FIG. 174.—A dissection showing excessive pneumatization or hollowing out of the maxilla by the maxillary sinus. All of the recesses of the sinus are extensively developed; the lacrimal protuberance prominent.

the osseous nasolacrimal canal is caudalward, lateralward and dorsalward. As a rule, the osseous nasolacrimal canal is illustrated in text-books as coursing in an almost vertical plane. A study of a large series of specimens has convinced the author that the true plane of the canal is seldom, if ever, vertical in the exact coronal plane, but that it is projected in a decidedly oblique plane from the lacrimal fossa to a variable point on the medial aspect of the alveolar process of the maxilla, corresponding to the interval between either the second premolar and the first molar, the first and second molars, or even as far dorsally as the interval between the second and third molar teeth.

The osseous nasolacrimal canal courses in the lateral nasal wall between the ventral portion of the middle nasal meatus and the maxillary

sinus, conforming more or less closely to the vertical confines of the middle meatus (Fig. 197). Not infrequently the canal throws a portion of the mesial or nasal wall of the maxillary sinus into a columnar relief (Figs. 102 and 174). The thickness of bone intervening between the maxillary sinus and the osseous nasolacrimal canal varies from a papery thinness to 2 or 3 mm. It is especially thin when the maxillary sinus develops extensively into the frontal process of the maxilla in the formation of the infraorbital or prelacrimal recess. Moreover, the nasolacrimal canal and the lacrimal fossa come into intimate relationship with certain anterior ethmoidal cells. The author observed also a number of instances in which the frontal sinus in addition to pneumatizing into the nasal bone extended laterally and caudally into the frontal process of the maxilla, thereby establishing most intimate relationships with the lacrimal fossa and its contained lacrimal sac.

The Lacrimal Ducts (ductus lacrimales).—The lacrimal ducts or canaliculi begin by minute openings, the *lacrimal puncta*, which normally either surmount or are placed on the sides of the conical *lacrimal papillæ* located on the free borders of the eyelids, the upper about 6 mm. and the lower about 8 mm. from the medial palpebral commissure (internal canthus). The lacrimal ducts consist of vertical and horizontal portions with dilatations or ampullæ at the genua or bends. The ducts average from 8 to 10 mm. in their total length; 0.1 to 0.2 mm. in diameter at the puncta, 1 mm. at the genua and 0.5 to 0.8 mm. in the horizontal portions. Irregularities and sacculations are not uncommon (Fig. 178). The inferior lacrimal duct is almost invariably longer than the superior duct, with its punctum and papilla farthest removed from the medial palpebral commissure.

Each lacrimal duct has a lining of stratified squamous epithelium resting upon a sparse tunica propria rich in elastic fibers. The orbicularis palpebrarum muscle strengthens the ducts. Some of these muscle fibers parallel the horizontal limbs and others encircle sphincter-like the vertical limbs of the ducts.

The horizontal portions of the lacrimal ducts communicate with the lacrimal sac in varying ways: (*a*) the ducts may unite into a short, narrow common duct and this in turn establish communication between the lacrimal ducts and the lacrimal sac (the usual way of communication); (*b*) the ducts may empty separately into an apparent diverticulum of the lacrimal sac—the superior sinus (Maier) of the lacrimal sac (this diverticulum may, however, be thought of as a wide common duct of the lacrimal ducts); (*c*) the ducts rarely empty separately into the lacrimal

sac, *i.e.*, there is neither a common duct nor a diverticulum from the lacrimal sac.[1]

The distal ends of the lacrimal ducts do not bear an intimate relationship to the nasal fossa or the paranasal sinuses. The relations of the proximal or terminal ends of the ducts are essentially those of the lacrimal sac which will be discussed in subsequent paragraphs.

The Lacrimal Sac (saccus lacrimalis) and the **Nasolacrimal Duct** (ductus nasolacrimalis).—The membranous lacrimal sac for the most

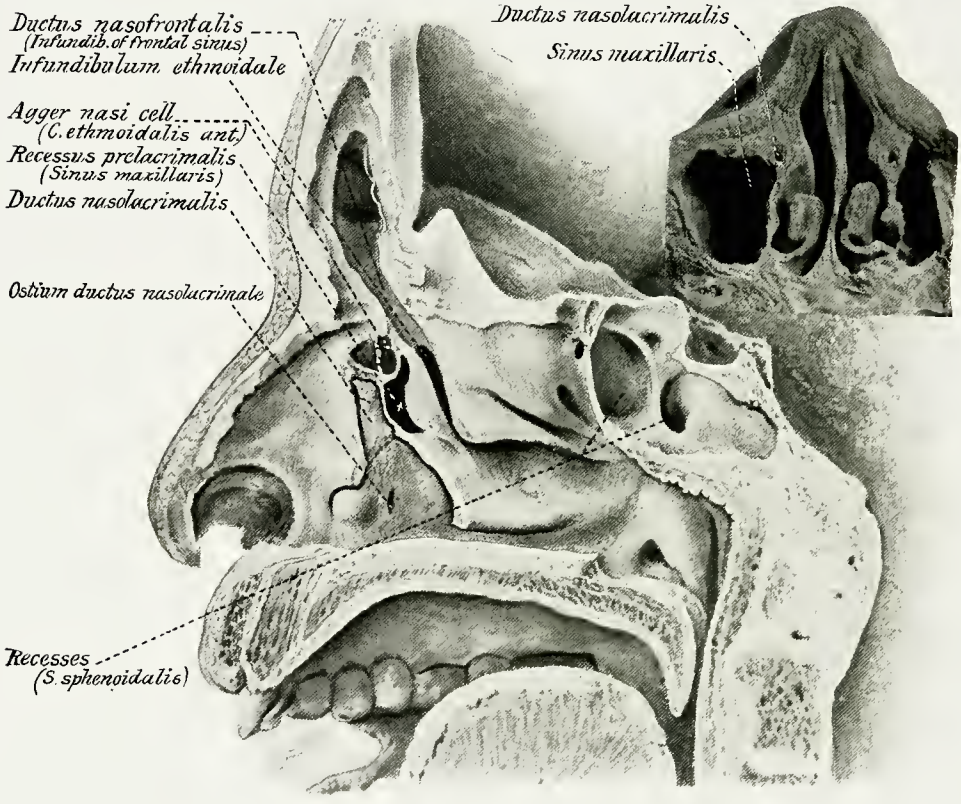

FIG. 175.—A dissection of the lateral nasal wall with especial reference to the nasolacrimal duct, the lacrimal sac (indicated by dotted outline, in white), the agger nasi cell, and the prelacrimal recess of the sinus maxillaris.

The inset is a transection showing the relations of the nasolacrimal duct.

Note the extension of the sphenoidal sinus beneath and dorsal to the hypophyseal fossa in the large figure.

part occupies the shallow lacrimal fossa, extending, however, for a greater or less distance into the upper end of the lacrimal canal. It may be considered the upper dilated extremity of the nasolacrimal duct and is

[1] J. Parsons Schaeffer: Variations in the Anatomy of the Nasolacrimal Passages, Annals of Surgery, August, 1911.

bridged over by the palpebral fascia which extends from the anterior to the posterior lacrimal crests. Moreover, it is covered by the medial palpebral ligament, fibers of the orbicularis palpebrarum, and at places merely by skin and subcutaneous tela. The upper rounded extremity or fornix of the lacrimal sac is located at varying distances above the medial palpebral ligament. On the dorsolateral aspect of the sac where the medial palpebral ligament crosses is located the orifice (or orifices) of the united lacrimal ducts. This orifice is usually located from 2 to 5 mm. from the extreme top or fornix of the lacrimal sac.

As a rule, the lacrimal sac merges imperceptibly with the nasolacrimal duct, save for a slight constriction—*the isthmus*. The major portion of the nasolacrimal duct is entirely encased by bone, *e.g.*, the nasolacrimal canal. In many instances the nasal end of the nasolacrimal duct is continued for a considerable distance beyond the nasal end of the osseous nasolacrimal canal within the mucous membrane of the lateral wall of the inferior meatus. This extension accounts for the discrepancy in length between the osseous nasolacrimal canal and the membranous nasolacrimal duct; moreover, divides the latter into *osseous* and purely *membranous* segments. The lacrimal sac measures on the average 12 mm. in its vertical plane and from 2 to 5 mm. in its transverse. Owing to the varied location of the nasolacrimal ostium in the inferior meatus, the length of the nasolacrimal duct is necessarily inconstant, varying from 10 to 28 mm. The diameter of the nasolacrimal duct is not uniform, measuring at the isthmus or point of transition from the sac to the duct but 3 mm.; becoming wider below this point it averages about 5 mm. in its ventrodorsal diameter and 4 mm. in its transverse diameter.

As stated above, the lacrimal sac and the nasolacrimal duct frequently merge in such a manner that the limitations of the sac can only arbitrarily be determined. However, not infrequently the lacrimal sac is very much wider than the nasolacrimal duct at the junction point, making the extent of the sac very obvious. Again, the lacrimal sac and the nasolacrimal duct instead of merging in a linear fashion are joined side to side in an indirect continuity, the fornix of the nasolacrimal duct appearing dome-like at the side of the lacrimal sac (Fig. 178). It is, of course, obvious that it is utterly impossible in the latter type to pass a lacrimal probe from the lacrimal sac into the nasolacrimal duct wihout making artificial openings by the advancing probe. On the other hand, the lacrimal probe is passed from the lacrimal sac into the nasolacrimal duct with relative ease when they are in direct linear continuity (Fig. 180).

The *fibro-elastic walls* of the lacrimal sac partake of the nature of a

lymphoid tissue and are connected with the periosteum by a loose areolar stratum containing a dense plexus of small veins. These anatomic factors account for the ready and marked congestion of the sac following trauma and infection. The lacrimal sac is lined with a double layer of columnar epithelial cells, some of which are ciliated. Here and there branched tubular glands are encountered. The nasolacrimal duct likewise is fibroelastic and separated from the surrounding periosteum by a loose tissue rich in veins. It is lined by columnar epithelial cells. Small branched tubular glands are found, especially as the duct nears its nasal termination.

Nasolacrimal Duct Diverticula and Valves.—It is generally believed that the walls of the nasolacrimal duct are always regular and that the

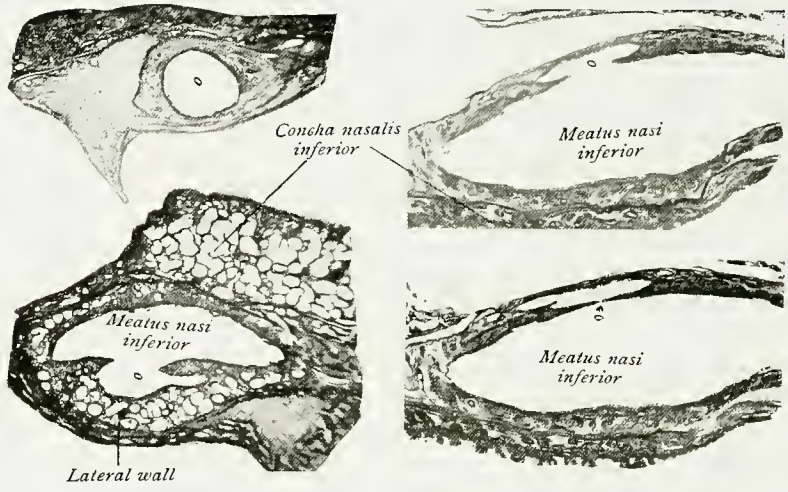

FIG. 176.—Photographs of transections of the nasolacrimal duct at the point of communication with the inferior nasal meatus; that is, at the level of the ostium nasolacrimale (*O*). The sections are from adults and are magnified from 2 to 4 times. (*After J. P. S.*)

lumen of the duct presents a more or less uniform cylindrical outline. Indeed, this is what one gathers from many text-books and from the average gross dissection of the channel. However, serial sections of the duct and reconstructions of its lumen at once show the fallacy of this belief.

Admittedly, a large number of nasolacrimal ducts have regular and more or less uniform walls. The formation of valve-like folds by the mucous membrane of the nasal duct in the upper and middle thirds has been frequently described. Krause and Beraud described a valve at the junction of the lacrimal sac and the lacrimal ducts. Careful study indicates that in many cases the so-called valve is merely a simple elevation of mucous membrane. However, the mucous membrane may be sufficiently reduplicated to form a true valve. The writer agrees with Boch-

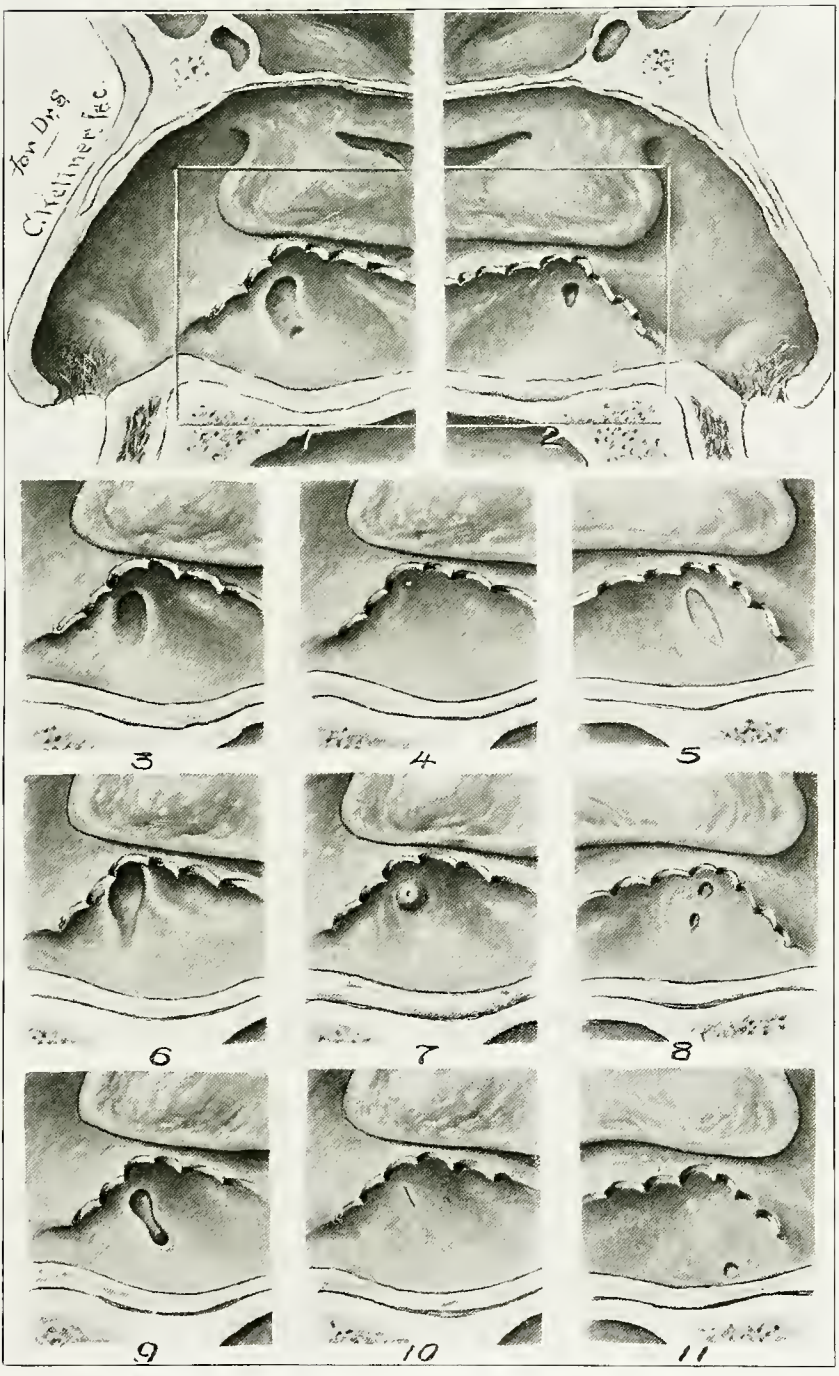

FIG. 177.—Drawings of actual dissections illustrating various types of ostia nasolacrimalia encountered in this study. The reader is referred to the text for a further consideration of them. The concha nasalis inferior is partly cut away so as to expose for study the manner of communication between the ductus nasolacrimalis and the meatus nasi inferior.

dalek that the opening of the lacrimal ducts may be placed in the center of a diaphragm-like lamina of mucous membrane. Again, one encounters many specimens in which there is no evidence whatsoever of mucosal plicæ or valves. Additional valves have been described for the mid-portion of the nasolacrimal duct. These folds of mucous membrane are usually of minor importance and may occur in nasolacrimal ducts presenting regular walls.

Recent investigations by the author indicate that many nasolacrimal ducts present lumina of very irregular contour, some even more or less tortuous in course. Minor irregularities, as stated above, are at times due to mere folds in the mucous membrane. In many instances they are of little moment. Again, they may form definite bridges along the walls of the duct. Entirely apart from these minor irregularities, *diverticula or direct outpouchings* of the nasolacrimal duct are not uncommon. They vary from those of insignificant size to those of relatively large dimensions. In studying cross sections of the nasolacrimal duct one is at times puzzled to explain what are apparently two ducts lying side by side. However, by following the sections serially one finds that one cavity sooner or later communicates with the other, *e.g.*, one turns out to be the nasolacrimal duct proper and the other a diverticulum from it (Fig. 172). These diverticula must be very important clinically since they are so located that they readily retain infectious material within their confines. Indeed, they may be important factors in the chronicity of pathologic conditions of the nasolacrimal duct. Owing to the irregularity of the lumen of the nasolacrimal duct and the presence of large diverticula, it is obvious that false passageways are repeatedly made by operators when they pass the lacrimal probe.

The diverticula are lined with a mucous membrane similar to that lining the main duct, and at the ostia of the diverticula the mucous membranes of the main duct and diverticula are directly continuous, both grossly and histologically. Genetically, the diverticula are, doubtless, the result of canalization of auxiliary lateral buds which grow from the solid cord of epithelial cells representing the rudiment of the nasolacrimal passageways. It must, therefore, be concluded from the evidence at hand that the diverticula from the nasolacrimal duct are of congenital origin and are not acquired in later life.[1]

The Nasal and Paranasal Relations of the Membranous Lacrimal Passageways.—The relations between the anterior ethmoidal cells and

[1] J. Parsons Schaeffer: Nasolacrimal Duct Diverticula and Their Genetic Significance, The Anat. Rec., Vol. 9, 1915.

lacrimal sac are more or less variable. Very commonly, however, two or more anterior ethmoidal cells (frontal and infundibular) immediately adjoin the dorsal and medial aspects of the lacrimal sac. Indeed, the osseous walls separating the mucous membranes of the ethmoidal cells and the lacrimal sac very frequently under normal conditions show dehiscences. At times ethmoidal cells crowd for a considerable distance forward along the lateral border and over the cupola of the lacrimal sac. Even more common is the extension of anterior ethmoidal cells over the medial or nasal side of the lacrimal sac and the beginning of the nasolacrimal duct. Cells in the latter position usually grow from the infundibulum ethmoidale (infundibular cells). However, at times extensions of ethmoidal cells from the frontal recess are found between the lacrimal sac and the middle nasal meatus. When practising endonasal dacryocystotomy these cells must, of course, first be ablated before the osseous walls of the lacrimal sac and the ocular end of the nasolacrimal duct can be reached (Fig. 175). Two lamina of bone intervene in such cases between the nasal fossa and the lacrimal sac and duct. Not infrequently, the entire wall of the lacrimal fossa is pneumatized by ethmoidal cells, some of which may extend for a variable distance along the ocular end of the nasolacrimal canal. These cells arise variously from the infundibulum ethmoidale and the frontal recess and extend into the agger nasi, the uncinate process, the frontal process of the maxilla and the lacrimal bone.

The nasolacrimal duct lies adjacent to the maxillary sinus and very frequently throws into relief the nasal wall of the sinus in the form of a cord-like swelling which corresponds to the sinus side of the osseous nasolacrimal canal. It is particularly *the infraorbital* or *prelacrimal recess* of the maxillary sinus that bears the most intimate relationship to the nasolacrimal duct and lacrimal sac. Unless one bears this extension of the maxillary sinus in mind in endonasal surgical procedures, the maxillary sinus is readily opened into instead of the osseous nasolacrimal canal and the nasolacrimal duct (Fig. 175).

As stated elsewhere, the frontal sinus usually does not bear an intimate relationship to the nasolacrimal passageways. When, however, the frontal pneumatization extends into the nasal bone, the frontal process of the maxilla and the lacrimal bone beyond the confines of the suture line separating them from the frontal bone, the frontal sinus will bear a direct relationship to the lacrimal fossa with its contained lacrimal sac.

The Nasolacrimal Ostium (ostium nasolacrimalis).—The ostium of the nasolacrimal duct is located from 15 to 20 mm. dorsal to the limen nasi and from 30 to 40 mm. from the nares (anterior nares). It is frequently

found at the most cephalic point of the inferior nasal meatus, that is, immediately caudal to the point of attachment of the inferior nasal concha to the lateral nasal wall. When in this position, the nasolacrimal ostium usually presents a wide open mouth owing to the osseous supporting ring. However, it is equally common that the ostium of the nasolacrimal duct is located relatively far below the attached point of the inferior concha, the distance varying from 0 to 10 mm. Between these two extremes one encounters ostia at various distances caudal to the attached border of the inferior nasal concha.

The nasolacrimal ostium is usually a single opening. However, duplicate and triplicate communications between the inferior nasal meatus and the nasolacrimal duct are not infrequently met with. A study of a large series of specimens convinces the observer that there is no unvarying typical form of ostium, but that several normal anatomic types are equally common. Indeed, it cannot be gainsaid that the notion of an ideal typical form must be abandoned more or less generally and in its place substituted the belief and knowledge of normal anatomic types. A reference to Fig. 177, in which are represented actual delineations of human nasolacrimal ostia, will indicate a number of the fundamental anatomic types that are encountered. The belief that *all* nasolacrimal ostia are provided with a mucosal valve (plica lacrimalis) or the so-called valve of Hasner must be abandoned. When the nasolacrimal duct terminates immediately caudal to the attached border of the inferior nasal concha, its ostium almost invariably stands permanently open, wide-mouthed and unguarded by a valve-like structure (see Nos. 1, 3, 6 in Fig. 177). In the type in which the nasolacrimal duct passes through the nasal mucous membrane rather obliquely, the ostium is slit-like and in a sense merely potential. In these cases the ostium may be said to be guarded by a fold of mucous membrane, that is, a plica lacrimalis of Hasner (Fig. 177, Nos. 5, 10). Occasionally the nasal end of the nasolacrimal duct pushes nipple-like into the inferior nasal meatus; surmounting the nipple is located the nasolacrimal ostium (Fig. 177, No. 7). At times the nasolacrimal ostium proper is more or less open and somewhat guarded by a plica lacrimalis. Extending from the ostium toward the floor of the nose is a fairly deep, gutter-like groove which tends to become deeper and deeper as one approaches its caudal limits (Fig. 177, No. 9). In the type of ostium shown in No. 5 of Fig. 177 the slit-like aperture becomes shallower and shallower as its caudal limits are reached and is in this respect unlike No. 9.

The nasolacrimal ostium is at times exceedingly small (Fig. 177, Nos.

4, 10, 11) and wholly inadequate as an efficient drainage orifice. These stand in marked contrast to the large and ever open ostia shown in Nos. 1, 3, 6 of Fig. 177. It is the latter ostia that are so easily located and probed from the nasal end of the nasolacrimal duct and that escape collapse from enlargement of the inferior nasal concha. On the other hand, it is the slit-like type of ostium located in the lateral wall of the inferior nasal meatus that are located and probed with difficulty and readily compressed by enlargement of the inferior nasal concha, occluded by hypertrophy or congestion of the mucous membrane. Indeed, in those cases of persistent nasolacrimal infection despite treatment the type of nasolacrimal ostium may be an important factor in the chronicity of the ailment.

Concluding Remarks.—Not to minimize the important connections, both anatomically and in disease, between the conjunctival culdesac and the nasolacrimal passageways, the etiological connections between disease of the latter and the nasal fossa and paranasal sinuses are generally recognized as of paramount importance. This is in comformity with the very intimate anatomic relationships that exist. At best but papery laminæ of bone intervene between the ethmoidal labyrinth and the orbit and between the ventral portion of the ethmoidal labyrinth and the lacrimal sac and the nasolacrimal duct. This is also equally true of the maxillary sinus in many instances. Indeed, congenital dehiscences in the bony "party-walls" are extremely commonplace. Moreover, the abundant network of lymphatic vessels are vitally important in establishing relations between the mucous membranes of the nasal and the nasolacrimal fields. Again, the dense venous plexuses of the nasal mucous membrane establish connections with the venous plexuses of the paranasal sinuses and those surrounding the lacrimal sac and the nasolacrimal duct. The venous plexuses of the nasolacrimal passageways connect also with the facial, infraorbital and ophthalmic veins; and as Zuckerkandl has shown, a lacrimo-facial vein connects with a larger vein emerging from the region of the anterior ethmoidal cells and passing through the lacrimal bone. These anatomic features must be of the greatest importance in the spread or extension of disease from the nasal fossa and the related paranasal sinuses to the lacrimal sac and the nasolacrimal duct and vice versa.

The direct communication of the nasolacrimal duct with the inferior nasal meatus and the direct continuity of the mucous membranes through the ostium nasolacrimale is of equally great importance in this connection. The ostium is frequently very large, from 5 to 7 mm. in diameter, standing permanently open, thereby inviting infection from the nasal fossa. Again,

the ostium may be so small that adequate drainage of the duct is utterly impossible, or the ostium if located in the mucous membrane of the inferior nasal meatus may be readily encroached upon and shut off by pathologic nasal states. In the nasolacrimal ostia which are permanently open and unguarded by true mucosal valves, air and fluids readily find their way into the nasolacrimal duct. It has been shown that during

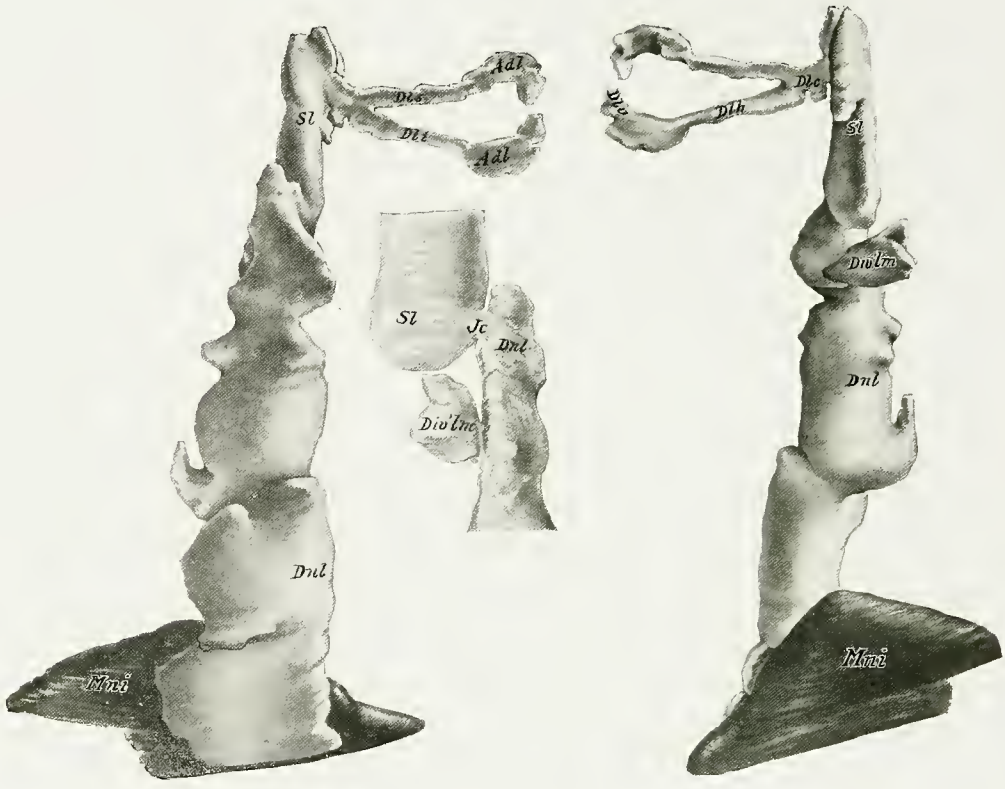

FIG. 178. FIG. 179.

FIGS. 178 and 179.—Reconstruction of the nasolacrimal passageways of an adult aged 65 years. Fig. 178 represents a medial view and Fig. 179 a lateral view of the model. Especially note the irregularity and the diverticula of the nasolacrimal duct.

The inset accompanying Fig. 178 shows the details of the side to side union of the lacrimal sac and the nasolacrimal duct; moreover, illustrates the large bud-like diverticulum from the nasolacrimal duct. ×3.2.

Sl = Saccus lacrimalis; *Dls* = Ductus lacrimalis superior; *Dli* = Ductus lacrimalis inferior; *Adl* = Ampulla ductus lacrimalis; *Dlv* = Ductus lacrimalis verticalis; *Dlh* = Ductus lacrimalis horizontalis; *Dlc* = Ductus lacrimalis communis; *Dnl* = Ductus nasolacrimalis; *Mni* = Meatus nasi inferior; *Div'lm* = Diverticulum of the nasolacrimal duct; *Jc* = Junction channel between the lacrimal sac and the nasolacrimal duct.

violent blowing of the nose particles of secretion are forced upward through the nasolacrimal duct into the lacrimal sac. Aubaret observed the ascent of very minute particles of tobacco-snuff as far as the lacrimal puncta.

In some cases true and efficient mucous-membrane valves guard the nasal end of the nasolacrimal duct. It would appear in such cases that the nasolacrimal passageways would be safeguarded in large measure from the passage of infectious-laden fluids and air into them from the inferior nasal meatus, particularly in violent blowing of the nose (Fig. 177).

Other factors being equal, it would seem from an anatomic viewpoint that an infected nasolacrimal duct and lacrimal sac would yield most readily to treatment in those cases in which the nasolacrimal ostium is large, permanently open-mouthed and unobstructed by anatomic conditions of the inferior meatus; moreover, in which the nasolacrimal duct is free of mucosal ledges and diverticula. On the other hand, one would expect infected nasolacrimal passageways to resist treatment and the ailment to enter the stage of chronicity in those anatomic types in which the nasolacrimal duct contains diverticula (often without gravity drainage), and nasolacrimal ostia of small and inadequate size for efficient drainage; moreover, a nasal ostium or aperture so located that it is readily influenced by conditions of the inferior nasal meatus. The *success or failure of non-surgical treatment of the diseased nasolacrimal passageways is largely dependent upon the anatomic type of nasolacrimal duct and ostium encountered.* Indeed, here as elsewhere in the body the "*anatomic type*" looms up before the physician as an important factor in treatment and prognosis.

FIG. 180.—Reconstruction of the nasolacrimal passageways of an adult aged 60 years. Note the regularity of the nasolacrimal duct and the gradual mergence of the lacrimal sac into the nasolacrimal duct at the constriction or isthmus. × 3.2.

Abbreviations as in Figs. 178 and 179.

If one can be guided by clinical reports much success has attended the endonasal operations upon the nasolacrimal duct and lacrimal sac when the caudal portion of the duct is stenosed or its ostium of communication

with the inferior meatus is blocked by pathologic states or is normally of inadequate size. Toti's endonasal operation on the lacrimal sac and West's endonasal window resection of the nasolacrimal duct cephalic to the inferior nasal concha are now frequently practised. Moreover, new operations or modifications of those of Toti and West have been devised, particularly by Halle, Polyak, Mosher, Green, Wiener, Yankauer, Beck, etc. The nasolacrimal duct has also been operated upon through the maxillary sinus—the v. Eicken's operation. Exonasal operation, on the lacrimal sac are also frequently practised. Probing of the nasolacrimal passageways would seem ill-advised from an anatomic viewpoint owing to the very common irregularities and diverticula of the nasolacrimal duct, and the occasional side to side union of the lacrimal sac and the nasolacrimal duct. These anatomic conditions preclude the successful passing of the lacrimal probe in very many instances. The advancing probe doubtless leaves the lumen of the sac or duct either to re-enter the more caudal portion of the duct or to course between the membranous duct and the osseous canal. This leads to artificial openings and passageways and leaves the patient in a worse state than before. The successful cases are doubtless those in which the lacrimal sac merges gradually with the nasolacrimal duct and the latter is fairly regular in contour. Unfortunately there is no way of knowing what type of duct confronts the operator.

VIII—THE NASAL MUCOUS MEMBRANE

CHAPTER VIII

THE NASAL MUCOUS MEMBRANE

Conforming with the anatomy of the nasal cavity and its appendages the lining mucous membrane is divided into three more or less distinct regions, *e.g.*, that of the vestibule, the nasal fossa, and the paranasal sinuses. Moreover, the structure of the mucous membrane of the several regions presents characteristics common to the respective fields. In addition, the mucous membrane of the nasal fossa is histologically divided into two unlike portions, conforming thereby to the physiology of the individual parts.

The Nasal Vestibule

As a sort of an antechamber to the nasal fossa we have the nasal vestibule which corresponds very closely in its extent to the cartilaginous nasal wall. Its lining mucosa is often referred to as the *regio vestibularis* of the nasal mucous membrane. At the naris (nostril) the skin of the upper lip and the wing of the nose passes into the vestibule and for a distance retains its surface characteristics of a stratified flat epithelium with superficial horny cells. The skin characters, however, are lost about the middle of the vestibule, changing here to stratified flat epithelium with an absent horny layer, resting on an underlying connective-tissue propria. The epithelium of the forepart of the vestibule rests on a connective-tissue corium continuous with that of the skin. The fibrous tunica propria is richly provided with elastic fibrils, coarse, stiff hairs (vibrissæ), and sebaceous and sudoriferous glands. In the deeper part of the vestibule the connective-tissue propria contains mixed sero-mucous glands which replace the sweat glands.

The Nasal Fossa

Conforming with the double function of the nasal cavity proper there are two areas of the lining mucous membrane (Schneiderian or pituitary membrane) that differ in structure— the *pars respiratoria* and the *pars olfactoria*. The latter occupies a small portion of each nasal fossa, being confined to the cephalic third of the nasal septum, nearly the whole of the superior concha, a very small portion of the middle concha, and to the

extreme ventral extremity of the supernumerary ethmoidal concha that may exist cephalic to the superior concha. This delineation of the olfactory area is in close agreement with the extended researches of Read (Figs. 195 and 196), but is more extensive than the long-accepted olfactory area (about 250 sq. mm.) of Brünn. The remaining portion of the mucous membrane is devoid of olfactory elements and is, therefore, classed as respiratory.

The Respiratory Portion (pars respiratoria).—The stratiform flat epithelium of the nasal vestibule gradually assumes the characteristics of the respiratory mucous membrane, *e.g.*, a stratiform ciliated cylindrical epithelium. This transition in epithelium takes place laterally at the limen nasi (vestibuli), medially at the septal tubercle, and caudally (floor) somewhat dorsal to the above planes. Individual variations as to the exact place of the transition are encountered.

The nasal respiratory mucous membrane varies greatly in thickness in the several parts of the nasal fossa. Over the inferior concha, portions of the middle concha, and adjacent portions of the septum the membrane frequently reaches a thickness of several millimeters; elsewhere it may be considerably less than a millimeter. The thickness of the mucous membrane over the inferior and middle conchæ, etc., is largely dependent upon the degree of development within the tunica propria of the contained cavernous tissue (vide infra). Moreover, the membrane is intimately attached to the periosteum and the perichondrium of the bones and cartilages of the nasal fossa. However, considerable variation exists in the degree of the closeness of the connection in the several parts of the fossa. The respiratory mucous membrane readily thickens under pathologic conditions, often attaining a thickness from four to six times normal.

The stratiform ciliated cylindrical epithelium of the nasal respiratory mucosa rests upon a cribriform basement membrane. Ciliated cells extend the entire thickness of the epithelium; the slender ends being deeply placed, resting upon the basal membrane, and the more bulky ends with the attached cilia forming the free surface. The cilia are least developed over the superior and supreme conchæ. They attain a length of from 5 to 7 microns and produce a definite and characteristic current toward the choanæ (posterior nares). The spaces between the deeper parts of the stratiform cells are filled with irregularly columnar or conical cells. The latter rest on the basement membrane but never reach the free surface with their pointed apices. Moreover, in addition to the conical cells there are found between the ciliated cells, resting on the epithelial floor,

mucous-containing goblet cells. Many cellular elements are encountered that are in the various stages of conversion into goblet cells. Cement edges are demonstrable between the more superficial ends of the ciliated and mucous goblet cells. Migratory leukocytes are numerous among the epithelial elements.

The *basement membrane* (membrana propria) varies greatly in thickness. For the most part it is definitely developed and fairly well

FIG. 181.—Section of mucous membrane from the caudal portion of the concha nasalis media. Note the excessive number of glands. × 95.

marked; however, at places it is feeble and difficult of demonstration. Where best formed it may normally attain a thickness of 0.020 mm. or more. It is distinctly cribriform, permitting processes of connective-tissue cells and leukocytes to pass through the apertures into the superimposed epithelium. The apertures in the basement membrane are often referred to as basal canals, and as Schiefferdecker long since pointed out,

they contain connective-tissue cells and leukocytes, but strangely never blood capillaries.

The *tunica propria* superficially consists of loose fibro-elastic tissue, rich in cells, and here and there collections of lymphocytes, suggestive of a lymphoid tissue (lymphatic nodules), are found. Deeply, as the periosteum and perichondrium are approached, the tunica propria progressively contains more abundant networks of elastic fibers. There is

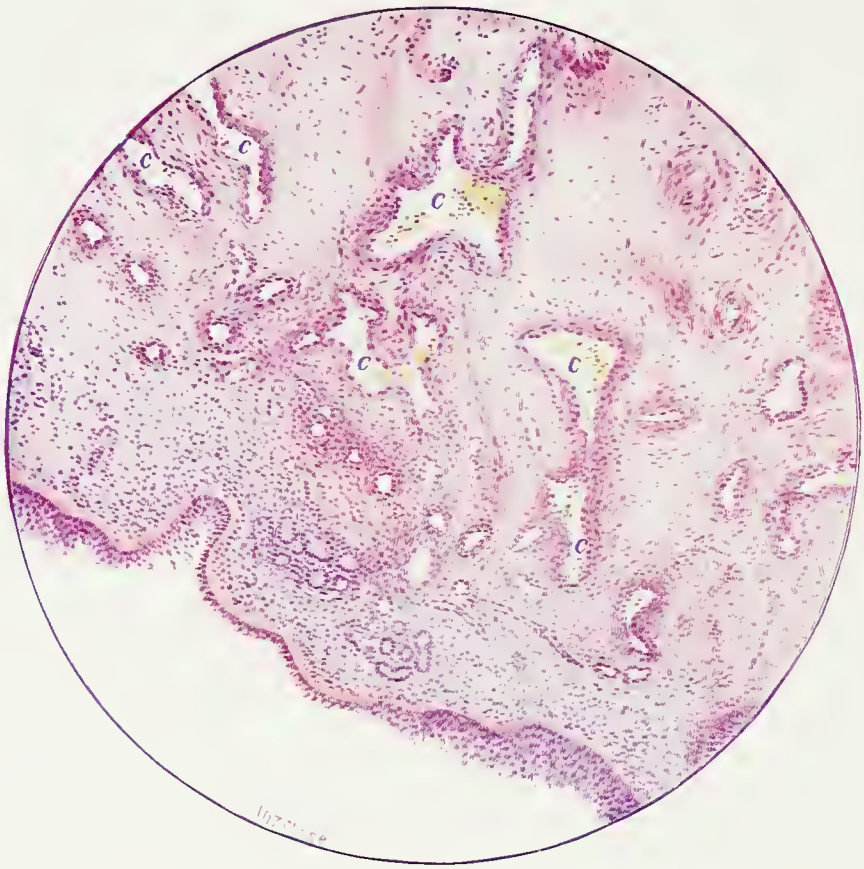

FIG. 182.—Section of mucous membrane from concha nasalis inferior. Note the fewer glands as compared with Fig. 181 and the large number of cavernous channels (*C*). × 95.

great variation in the amount of elastic fibers that are developed; at times dense, again sparse.

One of the characteristics of the nasal respiratory mucous membrane is the extremely rich blood supply of the tunica propria. The arteries of the deeper strata send their branches through the propria to form a capillary network beneath the epithelium and around the neighboring glands. From the arterial network the blood flows into a superficial

venous plexus, thence to a deeper one. Careful study indicates that these venous plexuses or blood-sinuses assume the character and rôle of an erectile tissue—the *plexus cavernosi concharum*. The latter is especially developed over the inferior concha (Figs. 159 and 183), along the dependent border and posterior extremity of the middle concha, and along adjacent portions of the nasal septum. In these positions one finds circular and longitudinal bundles of unstriped muscle embedded in the walls of the venous channels

FIG. 183.—Surface section of mucous membrane from the concha nasalis inferior as seen through the binocular microscope, showing the cavernous and erectile character of the tunica propria. × 12.

or vascular areas and the muscle bundles immeshed in a connective-tissue stroma containing elastica. Nerve reflexes control the filling and emptying of the cavernous tissue. It is well known that certain stimuli through the reflexes rapidly deplete the thickness of an engorged mucosa and that in certain psychic states similar depletion is experienced, and vice versa. The great masses of blood are doubtless of great importance in warming the inspired air. This, indeed, may be the chief function of the erectile tissue. Of course, a possible phylogenetic relationship must be kept in mind.

Numerous *glands* are found in the tunica propria of the respiratory mucous membrane. The simplest of these are short diverticula of the surface epithelium, dipping into the underlying tunica propria, which are for the most part lined with goblet cells. Moreover, many branched tubo-alveolar glands, resembling the glands of the lips, are found which are of a mixed nature. The chief ducts of these open on the free surface by minute orifices. The deeper portions of these glands branch and rebranch to bear the ovoid terminal alveoli. The latter are lined with mucous-secreting cells between which are groups of serous cells. In addition to these Kallius encountered purely serous glands (Figs. 181 and 182).

The Olfactory Portion (pars olfactoria).—The olfactory portion of the nasal mucous membrane is limited to a relatively small field in the

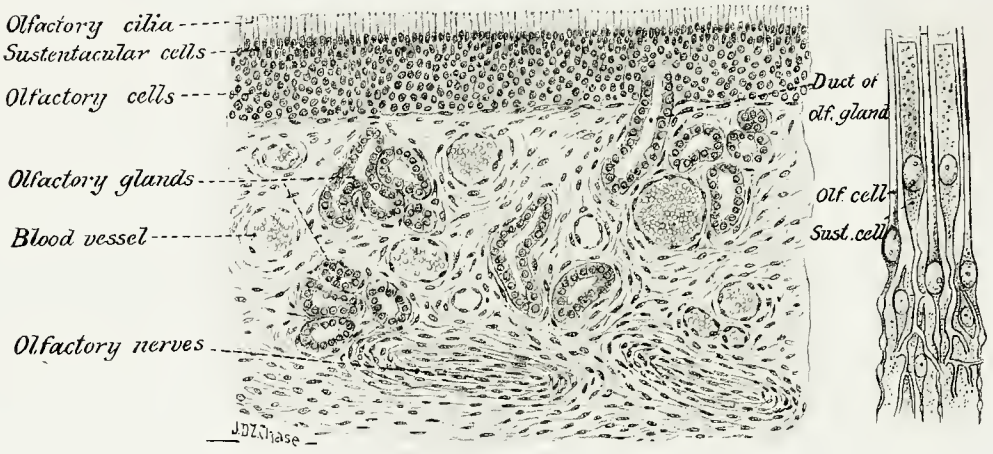

FIG. 184. FIG. 185.

FIG. 184.—Section of olfactory mucous membrane. × 300.
FIG. 185.—Isolated olfactory cells, greatly magnified. (*After Schulze.*)

nasal fossa as indicated at the beginning of this chapter and delineated in Figs. 195 and 196. It is demarked from the respiratory mucosa of the nasal fossa by its yellowish color and greater number of nuclei. However, at times the yellowish appearance is wanting.

The olfactory mucous membrane consists of a surface neuro-epithelium with a subjacent tunica propria. A definite and distinct basal membrane is wanting. The neuro-epithelium is composed of specific sensory (olfactory) cells and sustentacular (supporting) and basal cells. Collagenous and elastic fibers and tubulo-acinar serous glands (vide infra) are contained in the tunica propria (Figs. 184 and 185).

The *sustentacular cells* are tall, columnar, non-ciliated epithelial cells

and are considerably broader than the olfactory. Their nuclei contained in the outer and broader ends of the cells are ovoid and form a conspicuous nuclear stratum. There is a clear zone devoid of nuclei beneath the free surface of the epithelium. The deep ends of the supporting cells often terminate by branching into two or more processes, in the intervals of which are found basal cells. The cytoplasm of the supporting cells is granular and frequently contains a yellow pigment.

The *basal cells* are small, flattened pyramidal elements that form the deepest nuclear zone of the olfactory neuro-epithelial layers and are found between the branches of the sustentacular cells. Their nuclei are ovoid and their protoplasm finely granular. They may represent younger and additional forms of supporting cells of the olfactory mucosa.

The *olfactory cells* are the perceptive elements of the nasal mucosa. While the epithelium of the embryological olfactory pits is, strictly speaking, wholly olfactory, the latter designation ultimately applies to relatively few cells since the olfactory function is lost to most of the portions of the nasal fossæ. The cells that retain the olfactory characters and functions are known as neuroblasts. They remain in the walls of the nasal pits, become bipolar olfactory cells, and by central processes become connected with the brain. They represent morphologically the ganglionic cells on the dorsal (sensory) roots of the spinal nerves, and retain the primitive location of such sensory cells in the surface epithelium. The olfactory cells are unique in this regard among neuro-epithelial elements.

The olfactory cell bodies are bipolar, fusiform and contain spherical nuclei located between the deeper parts of the supporting columnar cells. The cells extend through the entire thickness of the neuro-epithelium. Their peripheral processes are short and pass to the surface of the mucosa through openings in the olfactory limiting membrane, each process giving rise to a hemispherical vesicle which in turn terminates in six to eight minute hair-like processes of fine cilia—the *olfactory hairs*. Moreover, the olfactory vesicles and processes are surrounded and in a sense supported by a "semi-fluid cuticle" believed to be secreted by the supporting cells. The central processes, slender and often tortuous, become grouped into about twenty bundles, the *olfactory nerves*, and pass through the foramina of the lamina cribrosa of the ethmoid bone into the anterior cerebral fossa, and after piercing the meninges of the brain they enter the olfactory bulb, there to synapse with the dendrites of the mitral cells (see page 332).

Embryologically the lateral evagination of the olfactory portion of the fore-brain is correlated with the invagination of the olfactory epithe-

lium from the ectoderm, and throughout life these two parts remain in close anatomical and physiological relationships.

The *tunica propria* is distinctly differentiated into a superficial and a deep stratum. The superficial stratum consists of a delicate reticulated tissue containing many irregularly round cells resembling lymphocytes. Indeed, the cells are at places so closely packed as to suggest small lymph follicles. On the other hand, the deeper stratum contains relatively few cells, but dense and heavy bundles of connective tissue, composed of collagenous and elastic fibers.

The *olfactory* (Bowman's) *glands* (glandulæ olfactoriæ) are contained within the tunica propria of the olfactory mucosa. They are of the branched tubular variety and open on the free surface of the mucosa by very narrow ducts that connect with saccular fusiform ampullæ into which the tubular alveoli open. The tubules are lined with cuboidal or conical cells containing many albuminoid secretory granules, not unlike those of the parotid glands. From the evidence at hand, the olfactory glands should be classed as serous, probably elaborating a specific secretion. The ducts of the glands are lined throughout the interepithelial course with independent flattened cells located between the surrounding epithelial elements.

The Paranasal Sinuses

The paranasal (accessory) sinuses are lined by mucous membrane directly continuous with that of the nasal fossa, including the maxillary, the frontal and the sphenoidal sinuses, and the ethmoid labyrinth. The mucous membrane lining the several paranasal sinuses and cells resembles that of the nasal fossa save that it is much thinner and contains fewer glands. Moreover, it does not assume the characteristics of an erectile tissue (Figs. 186, 187, and 188).

The mucous membrane of the paranasal sinuses and cells is composed of a stratiform ciliated columnar epithelium, invaded by numerous lymphoid elements, resting on a very delicate basal membrane and tunica propria. Indeed, the latter is firmly adherent to the underlying periosteum, especially so in the frontal and maxillary sinuses, less in the ethmoidal labyrinth and still less in the sphenoidal sinus. Unlike the mucous membrane of the nasal fossæ, that of the paranasal sinuses is poorly supplied with elastic fibers. Moreover, the glands, mucous in type, are few and scattered as compared with the glands of the nasal cavity proper. In the maxillary and sphenoidal sinuses the glands are most plentiful in the vicinity of the ostia of the cavities.

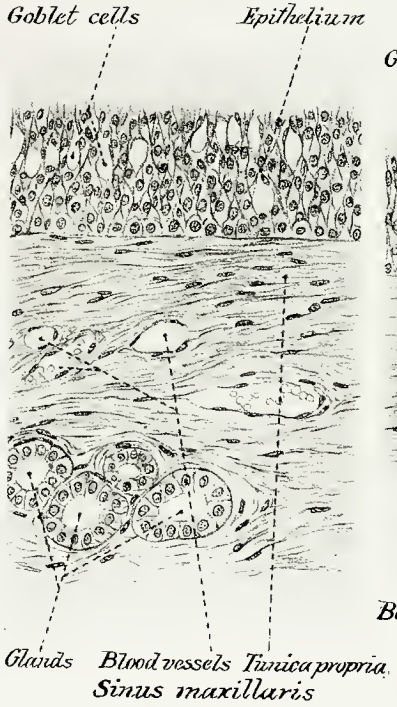

FIG. 186.—Section of mucous membrane of maxillary sinus. × 290.

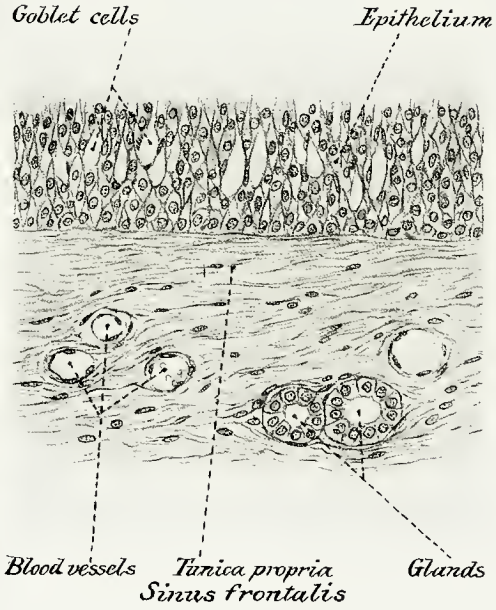

FIG. 187.—Section of mucous membrane of frontal sinus. × 290.

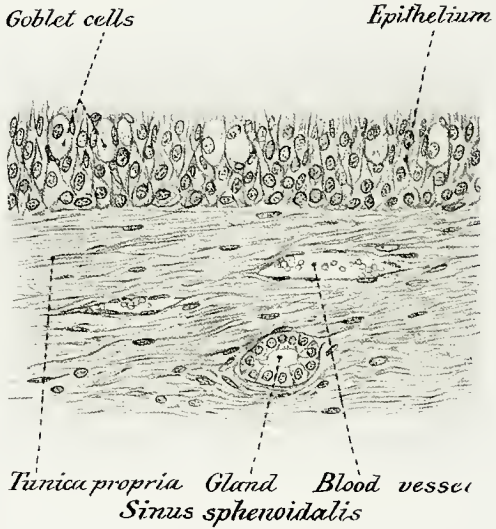

FIG. 188.—Section of mucous membrane of the sphenoidal sinus near its ostium or nasal aperture. × 300.

In spite of the extreme delicacy and thinness of the mucous membrane of the paranasal sinuses and its firm adherence to the periosteum, it is readily influenced and greatly thickened by pathologic processes. It is particularly prone to thickening, rapidly so, in the vicinity of the ostia of the maxillary and sphenoidal sinuses owing to the greater looseness of structures at these points.

The current produced by the cilia of the epithelium of the paranasal sinuses is toward their respective ostia or apertures of communication with the nasal fossa. As stated elswhere, the current produced by the cilia of the epithelium of the nasal fossa is toward the choana (posterior naris).

The Vomeronasal Organ

In adult man in the caudoventral portion of the nasal septum slightly cephalic and ventral to the orifice of the nasopalatine canal may occasionally be found a small ostium leading into a paired, blindly ending, mucosa-lined tubular sac. The latter courses dorsalward in the septal mucosa for a distance of from 2 to 6 mm., is lined with epithelium continuous with that of the nasal fossa, and has numerous glands opening into its lumen.

This rudimentary tubular canal is the homologue of a highly developed tubular organ, the vomeronasal organ (organon vomeronasale Jacobsoni), found in many quadrupeds in which the olfactory sense is particularly specialized. In the latter the organ is supported by a cartilage (Jacobson's cartilage). However, in man the cartilage of Jacobson is represented by a rudimentary strip of cartilage (the vomerine cartilage of Huschke) located caudal to both the septal cartilage and the rudimentary vomeronasal organ and does not give a supporting framework to the organ as it does in other animals.

As stated elsewhere, page 47, the vomeronasal organ in man apparently reaches its height of development by the twentieth week of embryonal life; after this retrograde changes in the epithelium occur (Fig. 189). In the adult the organ does not function in olfaction; no true olfactory cells are found in its mucosa. Most of the cells are of the sustentacular type. Some spindle cells (probably homologues of the olfactory cells) are found between the latter (especially on the medial wall), but do not reach the surface and apparently are not connected with the olfactory nerves in the adult. Read found olfactory connections in the child at birth.

In some other animals, *e.g.*, the rabbit, etc., the epithelium of the

vomeronasal organ is similar in structure to that lining the olfactory mucous membrane of the nose and receives branches of the olfactory nerve in addition to branches from the terminal and trigeminal nerves. In adult man, on the contrary, the vomeronasal organ seems to have to do wholly with general sensation and is supplied by the terminal and trigeminal nerves only.

FIG. 189.—Frontal section through the nasal fossæ and the nasal septum in the region of the vomeronasal organ of Jacobson. × 133.

THE SO-CALLED GENITAL SPOTS

Fleiss (1897) called the attention of rhinologists and gynecologists to what he considered an important relationship between certain areas of the nasal mucous membrane and the genitalia and adnexa. He believed the particular spots in the nasal mucosa to be limited to a very small area on the tuberculum septi, directly opposite the mid-portion

of the middle nasal concha, and to the ventral portion of the inferior nasal concha. Histologically, there is nothing apparently that characterizes these areas in the nasal mucosa, designated by Fleiss "the genital spots." Careful examination by the writer of the erectile portion of the nasal mucosa failed to reveal any characters common to the areas designated by Fleiss. Further study by a more perfected technic may show a difference in the histology of the so-called genital spots. This is, however, doubtful.

If the relationship between the nasal mucous membrane and the genitalia and adnexa becomes established in dysmenorrhea (not taking into consideration the obvious reflex connections between the olfactory and the genital organs), it is more than likely that the genital spots of Fleiss will be found to conform to the extent of the erectile-tissue portion of the nasal mucosa (see page 265).

IX—THE BLOOD- AND LYMPH-VASCULAR SYSTEMS OF THE NOSE AND PARANASAL SINUSES

CHAPTER IX

THE BLOOD- AND LYMPH-VASCULAR SYSTEMS OF THE NOSE AND PARANASAL SINUSES

The Arterial Supply

The arterial supply of the nose and paranasal sinuses is derived from both the external and internal carotid systems. *Branches of the ophthalmic* from the internal carotid and the *external maxillary* (facial) and the *internal maxillary* from the external carotid are concerned in the nasal supply. The final arterial distribution is effected by capillary plexuses or networks which supply the mucoperiosteum (periosteum, glands and tunica propria); one lying deep in the periosteum, a second surrounds and immeshes the glands, and a third forms a network immediately beneath the epithelium.

The Sphenopalatine Artery.—The main arterial supply to the nasal fossa and its appendages is distributed through the sphenopalatine artery (a. sphenopalatina), the terminal branch of the internal maxillary artery (a. maxillaris interna). The sphenopalatine enters the nasal fossa through the sphenopalatine foramen (foramen sphenopalatinum) which is located on the lateral nasal wall near the dorsal extremity of the superior nasal meatus and is formed by the articulation of the perpendicular plate of the palate bone with the caudal surface of the sphenoid bone. In the recent state the foramen is covered over by the nasal mucosa.

In the passage of the sphenopalatine artery through the foramen on the lateral nasal wall it is accompanied by branches of the sphenopalatine nerve, and immediately upon its appearance in the nasal fossa it gives off a small branch which aids in the supply of the mucous membrane of the sphenoidal sinus, and another variable branch whic at times replaces the pharyngeal artery and has a similar distribution (see pharyngeal artery). The main trunk of the sphenopalatine artery now divides into a large *medial* and a large *lateral* branch (Fig. 190).

The *lateral branch of the sphenopalatine artery* breaks up into a number of secondary rami, the *lateral posterior nasal arteries* (aa. nasales posteriores laterales), which ramify cranial-, caudal-, and ventralward from the choanæ to the nares and anastomose with the anterior and posterior ethmoidal arteries and with the lateral nasal branch of the external maxil-

lary (facial) artery. The group of lateral posterior nasal arteries form a rich plexus in the mucous membrane lining the nasal meatuses and conchæ, the maxillary and frontal sinuses, and the ethmoidal cells.

The *medial branch of the sphenopalatine artery*, the nasopalatine artery (a. nasopalatina), courses transversely across the roof of the nasal fossa to reach the medial nasal (septal) wall. Here the branch suffers dissociation into secondary rami, the *posterior nasal septal arteries* (aa.

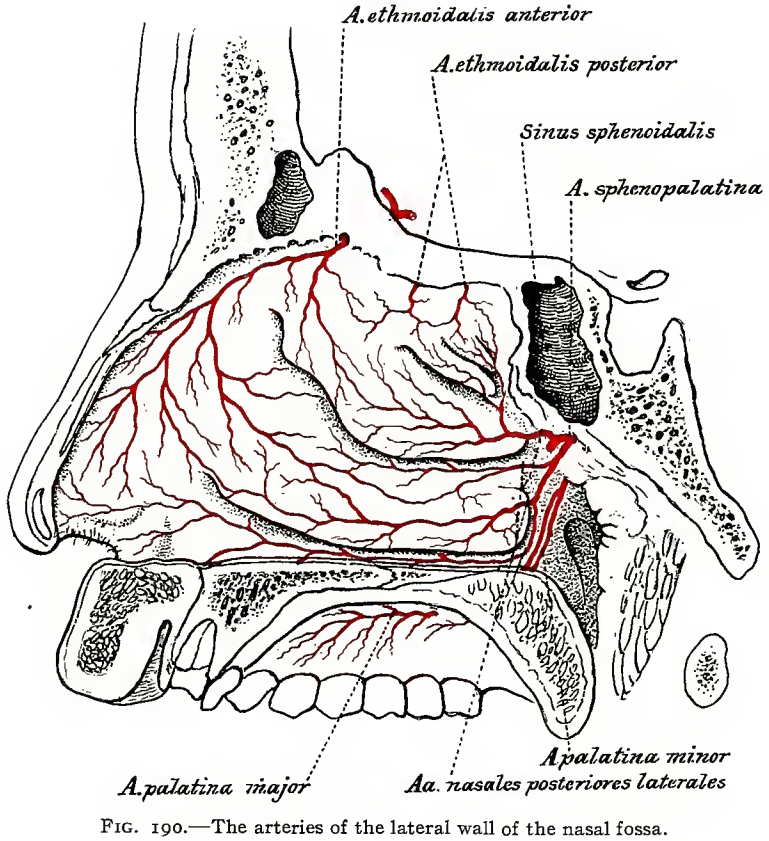

FIG. 190.—The arteries of the lateral wall of the nasal fossa.

nasales posteriores septi), which form a rich network beneath and in the septal mucous membrane. These arteries variously anastomose with the anterior and posterior ethmoidal arteries, with the septal branch of the superior labial artery, and with the great palatine (anterior branch of the descending palatine) artery near or within the incisive (anterior palatine) foramen. Some of the posterior nasal septal arteries are accompanied by the nasopalatine nerve in its course across the nasal septum to the incisive foramen (Fig. 191).

The Anterior and Posterior Ethmoidal Arteries.—The anterior and posterior ethmoidal arteries arise from the ophthalmic artery (a. ophthalmica) as the latter courses along the medial wall of the orbit. Occasionally the posterior ethmoidal arises from the supraorbital artery.

The *anterior ethmoidal artery* (a. ethmoidalis anterior), accompanied by the anterior ethmoidal branch of the nasociliary nerve, passes through the anterior ethmoidal foramen on the ventromedial aspect of the orbit into the anterior cerebral fossa. In its course ventralward along the

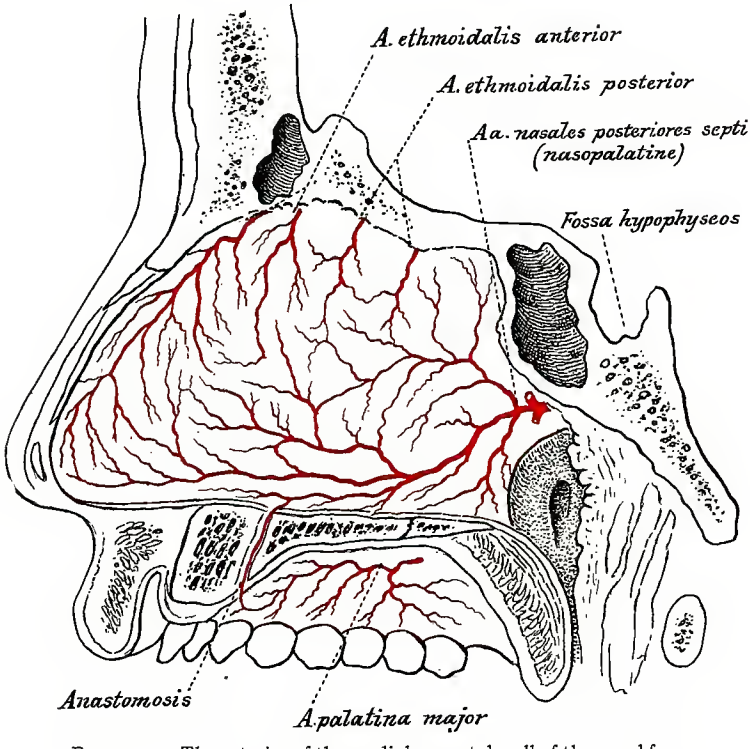

FIG. 191.—The arteries of the medial or septal wall of the nasal fossa.

cranial surface of the cribriform plate of the ethmoid bone, the anterior ethmoidal artery supplies branches to the dura mater and to the mucous membrane of the frontal sinuses and the anterior ethmoidal cells, and ultimately passes through a slit-like foramen at the side of the crista galli to reach the mucous membrane of the nasal fossa. Once in the nasal fossa the anterior ethmoidal artery descends, accompanied by the lateral branch of the nasal nerve, in a groove on the deep surface of the nasal bone and, finally, courses between the lateral nasal cartilage and the caudal (lower) border of the nasal bone to the tip of the nose. In the

nose the artery supplies branches to the nasal mucoperiosteum along its course and to the integument on the dorsum of the nose (Figs. 190, 191).

The *posterior ethmoidal artery* (a. ethmoidalis posterior) is smaller and less constant than the anterior ethmoidal above described. It passes through the posterior ethmoidal foramen on the dorsomedial aspect of the orbit and is distributed to the mucoperiosteum lining the posterior ethmoidal cells and the dorsal and superior portions of the nasal septum and the lateral nasal wall. Here the posterior ethmoidal branch of the ophthalmic artery and the sphenopalatine branch of the internal maxillary artery connect up in a plexiform anastomosis (Figs. 190 and 191).

The Descending Palatine Artery.—The descending palatine artery (a. palatina descendens), a branch of the internal maxillary, supplies small branches to the dorsal portion of the nasal fossa and by its direct ventral continuation—the *great palatine artery*, which courses forward in the roof of the mouth to ascend through the incisive foramen—supplies a portion of the nasal fossa in the neighborhood of the incisive foramen where it anastomoses with the *posterior artery of the septum nasi* (the nasopalatine artery).

The Pharyngeal Artery.—The pharyngeal artery (a. pharyngea), a small branch of the internal maxillary, courses dorsalward, accompanied by the pharyngeal branch of the sphenopalatine ganglion, through the pharyngeal canal (canalis pharyngeus) to the roof of the pharynx. From here the artery distributes small branches to the dorsal and superior portions of the nasal fossa, the roof of the pharynx, the sphenoidal sinus and the auditory tube.

The Infraorbital Artery.—The maxillary sinus, in addition to the blood supply from the lateral nasal branches of the sphenopalatine artery, receives abundant supply from the branches of the infraorbital artery (a. infraorbitalis).

The External Maxillary (Facial) Artery.—The nares (nostrils) of the nose are supplied by the *lateral nasal branch* of the external maxillary (facial) and by the *septal branch* from the superior labial (a. labialis superior or coronary artery). The external maxillary or facial artery continues along the lateral aspect of the external nose as the *angular artery* (a. angularis) and anastomoses with the true *terminal branch* (a. dorsalis nasi) of the ophthalmic artery. This anastomosis supplies the integument over the side and dorsum of the external nose.

The Venous Supply

The veins of the nose form a great network in the deeper parts of the tunica propria of the nasal mucous membrane, which in the respiratory

region over the middle and inferior nasal conchæ and the adjacent portions of the nasal septum assumes the character of a dense cavernous plexus. Elsewhere the erectile character of the network is less marked or absent altogether.

The venous blood is returned from the plexiform network by three chief pathways: ventrally into the anterior facial vein, dorsally into the sphenopalatine vein, and cranially into the ethmoidal veins. Injections show that the ethmoidal veins communicate with the ophthalmic vein and with the veins within the dura mater, including the superior sagittal

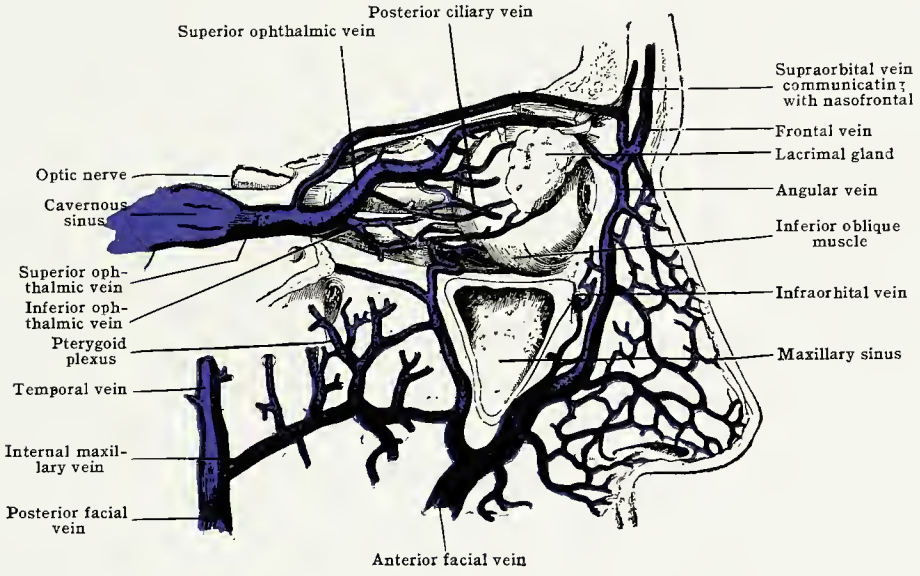

FIG. 192.—The veins of the nose and eye and their connections. (*After Quain.*)

dural sinus. Moreover, Zuckerkandl found that an anterior ethmoidal vein leads from the nasal mucosa and passes through the cribriform plate to end in the venous plexus of the olfactory bulb or in one of the veins on the orbital aspect of the frontal lobe of the brain. These venous communications must be a factor in the intracranial complications that frequently accompany or follow some cases of inflammation of the nasal cavities and paranasal sinuses (Fig. 192).

THE LYMPHATIC SUPPLY

The existence of lymphatics in the nasal mucosa was first satisfactorily demonstrated by E. Simon in 1859. He succeeded by puncture injections in demonstrating an extensive network of lymphatic vessels.

This network is continuous with the lymphatic vessels of the nasopharynx, the nasal vestibule and the cephalic and dorsal surfaces of the soft palate. Moreover, there is a lymphatic connection between the two nasal fossæ.

The Nasal Cavity.—The lymphatics of the nasal cavity ramify the entire mucoperiosteum, both olfactory and respiratory, including that of the septum. It has also been fairly well established that the lymphatic network extends into the paranasal (accessory) sinuses in communication with the nasal cavity. The lymphatic vessels are located in the connective tissue of the tunica propria and their richness is in direct proportion to the thickness of the mucosa. At places the mucosa

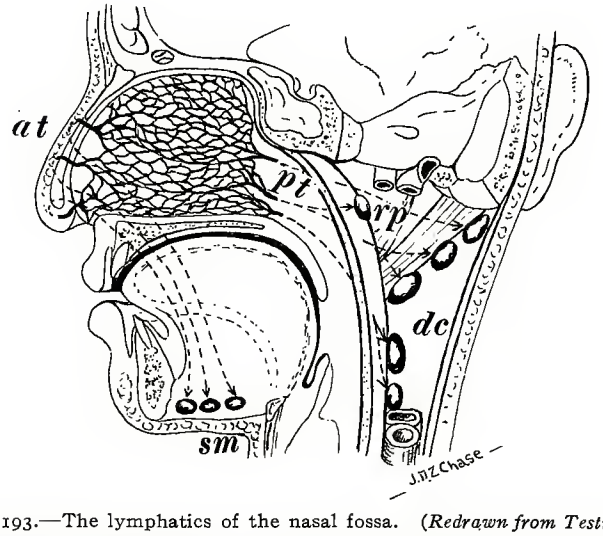

FIG. 193.—The lymphatics of the nasal fossa. (*Redrawn from Testut.*)

At = Anterior lymphatic channels; *Pt* = Posterior lymphatic channels; *Sm* = Submandibular or submaxillary group of lymphatic nodes; *Rp* = Retropharyngeal group of lymphatic nodes; *DC* = Deep cervical group of lymphatic nodes.

is infiltrated with lymphocytes and occasionally very minute solitary nodules are found. In man the main collecting vessels of the lymphatic network of the nasal fossæ form ventral and dorsal groups. The ventral (anterior) group vary in number and are found to course in the groove between the triangular cartilage and the bordering bone and between and ectal to the several cartilages of the external nose. In the subcutaneous tela they unite into several large trunks in relation with the facial nerve. These collecting trunks empty into the facial and the submandibular (submaxillary) groups of nodes. Furthermore, there is considerable anastomosis with the skin lymphatics of the external nose.

The lymphatic network in the region ventral and caudal to the

pharyngeal ostium of the auditive (Eustachian) tube receives drainage from a considerable portion of the nasal fossa. From this region go forth the largest and most important collecting trunks from the lymphatic network, to terminate in either the deep cervical chain or in the retropharyngeal nodes. It has been shown by Most that at whatever point the nasal mucosa is punctured, the retropharyngeal nodes are colored by the injected material. Sappey long since pointed out the involvement of the large lateral retropharyngeal nodes ventrad of the atlas in diseases of both the nose and the pharynx. The frequent infection of the retropharyngeal nodes is readily explained when one recalls their extensive lymphatic area. They receive as afferents almost all the collecting vessels from the nasal mucous membrane and from the cavities in connection with the nasal fossæ. Moreover, afferents from the lymphatic network of the cavity of the tympanum, the auditive tube, and the nasopharynx pass to these regional nodes (Fig. 193).

It would appear established that the subdural space directly communicates with the extracranial lymphatics and the perineural spaces of the olfactory nerve, etc. Schwalbe, Key and Retzius, and subsequently Cuneo, succeeded in injecting the nasal lymphatics from the subdural spaces. Furthermore, Key and Retzius reported success in injecting the nasal lymphatics from the subarachnoid spaces at the base of the brain. Confirmation of the latter is, however, lacking at this date and it is probable, according to other studies, that the subarachnoid space has no direct lymphatic connections. The perineural sheaths of the olfactory nerves are of interest in this connection. Key and Retzius found that when injecting the subarachnoid space the perineural sheaths of the olfactory nerves would frequently be injected. They found, however, that the true lymphatics did not communicate with these perineural sheaths, but had special passages through the lamina cribrosa and that they were often injected when the perineural sheaths were not injected. On the contrary, the perineural sheaths were at times injected and the lymphatics not.

Flexner, in discussing the mode of infection in epidemic meningitis, states that in all probability the micro-organism passes directly to the nervous system by way of the lymphatic connections between the nasopharyngeal mucosa and the meninges.

The Paranasal Sinuses.—There is little definite knowledge regarding the lymphatics of the paranasal (accessory) sinuses of the nose. Studies of Most indicate that the lymphatic drainage from all the paranasal sinuses and cells is into the retropharyngeal nodes. Clinical evidence bears out this conclusion.

The External Nose.—The lymphatic network of the external nose is very dense over the alæ and lobules and as it courses over the dorsum and the root of the organ. There is an anastomosis from side to side. As pointed out before, the lymphatic network of the external nose is continuous with the lymphatics of the nasal vestibule and the mucosa of the nasal fossæ. The collecting vessels arise from the cutaneous network in three groups, according to the studies of Küttner: (a) from the root of the nose they pass above the upper eyelid and terminate in the parotid nodes; (b) from the root and side of the nose they pass across the lower

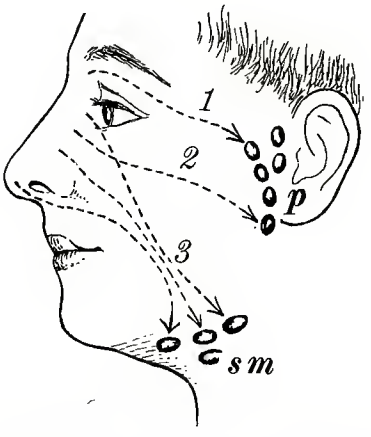

FIG. 194.—Schema of the lymphatics of the external nose. (*Redrawn from Testut, after T. et J.*)
1 = Superior group of lymphatic channels; 2 = Middle group of lymphatic channels; 3 = Inferior group of lymphatic channels; *p* = Parotid group of lymphatic nodes; *sm* = Submandibular (submaxillary) group of lymphatic nodes.

eyelid to the parotid nodes; (c) the third and most important group arise from the entire cutaneous portion of the external nose and terminate in either the facial or submandibular (submaxillary) group of nodes. Küttner was able by puncturing the integument of the external nose to distend the lymphatics of the mucosa of the nasal fossæ and to follow the injection to the dorsal surface of the soft palate (Fig. 194).

Further study of the nasal lymphatics is necessary in the light of certain clinical manifestations.

X—THE COMMON SENSORY AND THE SYMPATHETIC NERVES OF THE NOSE AND PARANASAL SINUSES

CHAPTER X

THE COMMON SENSORY AND THE SYMPATHETIC NERVES OF THE NOSE AND PARANASAL SINUSES

A. The Nerves of Common Sensation

The nerves of common sensation of the nose and its appendages are derived from both the ophthalmic and the maxillary divisions of the trigeminal nerve (n. trigeminus), *e.g.*, the nervus ophthalmicus and the nervus maxillaris, respectively. The sensory nerves to the nose are in reality peripheral processes of T-fibers which spring from the nerve cell bodies (perikaryons) of the semilunar (Gasserian) ganglion and pass to the nasal organ by way of the branches of the ophthalmic and maxillary trunks of the ganglion. The central processes of the T-fibers, on the contrary, pass into the brain stem, there to synapse at the nucleus of termination of the trigeminal nerve with neurons of the second order in the common sensory (afferent) pathway from the nose. The cell bodies of the semilunar ganglion together with the T-fibers with their central and peripheral processes constitute neurons of the first order in the common sensory pathway. It would appear established that the trigeminal nerve fibers rise up between the epithelial cells of the nasal mucous membrane and end free. The "Geruchsknospen" of Blaue and the "Epithelknospen" of Disse need re-investigation.

The Central Connections.—The sensory (terminal) nucleus of the trigeminal nerve is located in the pons lateral to the motor one (nucleus of origin of the masticator nerve) and beneath the brachium conjunctivum (superior cerebellar peduncle). It consists of an enlarged upper end, usually referred to as the *main sensory nucleus*, and an elongated, slender descending portion—the *nucleus of the spinal tract of the trigeminal nerve.* The latter extends through the pons and the medulla and becomes continuous with the dorsal part of the posterior column of gray matter of the spinal cord, particularly the substantia gelatinosa of Rolando. The main sensory nucleus receives the short ascending branches; the descending branches collectively forming the tractus spinalis which ends by terminals and collaterals in the several portions of the nucleus of the spinal

tract, extending through the pons, medulla and spinal cord to the level of the second cervical segment.

The cells of the sensory or terminal nucleus of the trigeminal nerve together with their processes constitute neurons of the second order in the common sensory pathway from the nose. The centrally directed processes or axons form a distinct bundle, the *trigeminothalamic tract*, which passes cranialward through the reticular formation and the tegmentum to end in a special portion of the thalamus by synapsing with the neurons of the third order in the pathway from the nose to the cerebral cortex. For the most part the fibers of the trigeminothalamic or central trigeminal tract decussate or cross to form the opposite paired tract, ascending dorsal to the medial fillet or lemniscus. A few fibers of the trigeminothalamic tract ascend to the thalamus uncrossed. From the thalamus impulses are carried over neurons of the third order to the somesthetic area of the cerebral cortex, the axons of which course by way of the internal capsule and the corona radiata, mostly on the side opposite from which the impulse initially started in the nose. Thus stimulation of the terminal nucleus of the trigeminal nerve leads to conscious sensations, often of a painful character. Some fibers of both the trigeminal nerve direct and from its terminal nucleus pass laterally into the cerebellum.

Axons from the nucleus of termination of the trigeminal nerve and collaterals from the trigeminothalamic tract in its course through the medulla are given to various motor nuclei, especially the facial, the masticator (motor of trigeminal), and the nucleus ambiguus (of the vagus and glossopharyngeal nerves) for simple reflexes. Moreover, some of the reflex or association axons from cells in the nucleus of termination of the trigeminal nerve contribute fibers to the medial longitudinal fasciculus, some of which are long and descend below the level of the second cervical segment, terminating in the gray substance of the spinal cord. Since one of the salient features of the medial longitudinal fasciculus is to associate the oculomotor, trochlear and abducent nuclei, the association axons from the trigeminal terminal nucleus coursing in the bundle doubtless are brought into relationship with the nuclei of the eye-moving muscles, and since the fasciculus becomes continuous with the anterior fasciculus proper of the spinal cord, relationship is also established between the association axons and the ventral horn cells of the cervical spinal segments.

Relations are also established between the central trigeminal fibers and their terminal nucleus and the vasoconstrictor, vasoinhibitor and secretomotor centers. Stimulation of the latter centers leads to unconscious sensations, resulting in divers reflex phenomena.

The somatic sensory fibers of the vagus, of the glossopharyngeal and of the pars intermedia of the facial nerves terminate in the nucleus of the spinal tract of the trigeminal nerve and their cortical impulses follow the trigeminothalamic tract. The descending somatic sensory fibers of the vagus, glossopharyngeal and facial (pars intermedia) nerves which terminate in the spinal tract of the trigeminal nerve, doubtless through the medium of associational or connecting neurons, establish relations with the nuclei of the motor cranial nerves in the medulla and with the ventral or motor horn cells of the high spinal cord.

B. The Sympathetic Nerves

Nerve impulses destined to determine the caliber of the blood-vessels and to control the mechanism of secretion in and about the nasal fossæ are transmitted by sympathetic efferent nerves. Both the cranial and the thoracolumbar sympathetics have to do with the nasal supply; the cranial brought about by sympathetic fibers contained in the pars intermedia of the facial nerve and the thoracolumbar by connections between the upper thoracic segments of the medulla spinalis (spinal cord) and the superior cervical sympathetic ganglion. Moreover, it is believed that certain impulses from the nasal mucous membrane reach the cerebrospinal nervous system over sympathetic afferent nerves.

The term "sympathetic"[1] is used advisedly since it is a term generally understood to apply to that portion of the peripheral nervous system which innervates the smooth or visceral muscles wherever located, the various glands of the body, and the striated muscle of the heart. It is not deemed profitable nor essential in this connection to discuss the detailed anatomy of the sympathetic nervous system. The reader is referred to special treatises on the subject. It must, however, be clearly understood that on the efferent (motor) side of the sympathetic system there are two orders of neurons connecting the cerebrospinal axis with the tissue or organ supplied. The neurons of the first order (preganglionic) have their cell bodies within either the brain or the spinal cord, the peripheral processes (axons) terminating by synapsing in sympathetic ganglia with the cell bodies of neurons of the second order (postganglionic), whose peripheral processes or axons extend to the parts to be acted upon. This stands in contrast to the single lower motor neurons of the somatic series of nerves in which the cell bodies are also located within the cerebrospinal axis, but whose axons

[1] The terms autonomic (Langley), vegetative (Myer and Gottlieb) and involuntary (Gaskell) are frequently applied to the sympathetic system. Langley limited the term sympathetic to apply to the thoracolumbar outflow. There is, however, no morphologic basis for this distinction.

go directly to the striated or voluntary muscles without further synapse. Furthermore, it is essential to recall that the vast majority of the cell bodies or perikaryons of the afferent or sensory sympathetic neurons are located in the ganglia on the dorsal roots of the spinal nerves and in homologous ganglia of certain cranial nerves. Cell bodies of a few afferent sympathetic neurons are apparently located in the extra-centrally placed sympathetic ganglia.

It is, therefore, obvious that the only anatomically independent units of the sympathetic nervous system, so far as a connection with the cerebrospinal nervous system is concerned, are the postganglionic neurons with cell bodies in the sympathetic ganglia and whose axons collectively course as pure sympathetic nerves or as sympathetic components of somatic nerves to the various parts of the body. Moreover, in spite of a certain peripheral autonomy in the physiologic responses of the sympathetic nervous system, the latter is in large measure regulated and controlled by the cerebrospinal nervous system, a control made possible by the intimate anatomic connections of the two systems.

Sympathetic Efferent Neurons.—A. Sympathetic efferent or motor fibers for the supply of the nasal fossæ and sinuses arise from a special nidus of cells located dorsal and medial to the facial nucleus in the reticular formation of the medulla. The *preganglionic fibers* from this nest of cells leave the medulla as constituent elements of the pars intermedia of the facial nerve (the glossopalatine nerve), and are distributed (1) by the chorda tympani and lingual nerves to the submaxillary ganglion and (2) by the great superficial petrosal nerve to the sphenopalatine (Meckel's, nasal) ganglion. From the cell bodies located in the sympathetic submaxillary ganglion go forth *postganglionic fibers*, vasodilator and secretory in function, to the submaxillary and sublingual salivary glands; and from the cell bodies in the sympathetic sphenopalatine ganglion issue *postganglionic fibers* (in the branches of the sphenopalatine ganglion, see page 307), vasodilator and secretory in function, to the mucous membrane (blood- and lymph-vessels and glands) of the nose and palate, the lacrimal gland, the tonsils, etc.

B. Sympathetic efferent (*preganglionic*) fibers with cell bodies located in the dorsolateral portion of the ventral horns of the upper four or five thoracic segments leave the spinal cord by the ventral roots of the corresponding spinal nerves and reach the ganglionated sympathetic cord by way of white rami communicantes. The axons of most of these preganglionic neurons, destined for the supply of the various parts of the head, ascend in the cervical sympathetic cord and

terminate by synapsing around the cell bodies of *postganglionic neurons* located in the *superior cervical sympathetic ganglion.* The latter neurons are variously vasodilator, vasoconstrictor, secretory, visceromotor (to the dilator pupillæ muscle) in function. They ascend by way of the cephalic plexiform extension of the superior cervical sympathetic ganglion and reach their destination by way of cranial nerves, especially the branches of the trigeminal. Some of these postganglionic neurons furnish vasoconstrictor, and probably additional dilator and secretory fibers, to the nasal mucous membrane.

Probably the pars intermedia and the cervical ganglionated cord carry both vasoconstrictor and vasodilator preganglionic fibers; but that the vasodilator fibers are most numerous and active in the pars intermedia and the vasoconstrictor in the cervical extension from the sympathetic (at least so far as the nasal mucous membrane is concerned) seems certain. Of course, when experimentally stimulating these nerves the work of the fewer and less active fibers may be wholly masked by the greater effect and number of antagonistic fibers. In general, throughout the body, the vasoconstrictor fibers are the most prominent, exercising a continual tonic effect on blood-vessels. However, while vasodilator fibers are fewer and less frequently seen in action, they do exist—striking illustrations are the chorda tympani in its action on the submaxillary gland; the nervi erigentes in the erection of the penis, clitoris, etc.; and the nerves to the erectile tissue of the nasal fossæ.

Sympathetic Afferent Neurons.—It is known that sympathetic afferent fibers with their cell bodies located in the geniculate ganglion are constituents of the pars intermedia of the facial nerve. Doubtless the peripheral processes of some of these neurons accompany and are a part of the great superficial petrosal nerve and pass through the sphenopalatine or nasal ganglion of Meckel to be distributed by way of the branches of the ganglion to the mucous membrane of the nasal fossa, the paranasal sinuses, and the neighboring parts. The central processes of the geniculate sympathetic cell bodies follow the trunk of the pars intermedia of the facial nerve into the medulla oblongata and while their central connections are not clearly established they presumably form additional synapse relations, either directly or indirectly, (1) with the vasoconstrictor center in the medulla; (2) with the vasodilator centers (particularly the centers of dilator fibers which accompany the pars intermedia of the facial, the glossopharyngeal and the cervical sympathetic), probably located variously in the medulla; (3) with the cardio-inhibitory center in the medulla; and (4) with somatic efferent neurons of the head and cervical regions.

Additional sympathetic afferent fibers from the nasal cavity and sinuses seemingly reach the spinal cord by way of the cervical sympathetic cord, with cell bodies located in the ganglia of the dorsal roots of the upper thoracic nerves. The central processes of these cell bodies establish additional synapse relations with efferent sympathetic (preganglionic) and efferent somatic neurons within the spinal cord.

The relations formed between afferent or sensory sympathetic neurons and efferent somatic and sympathetic neurons establish neuron arcs for reflexes. Moreover, afferent sympathetic neurons from the nose synapse either directly or indirectly (by intercalation of additional elements) with the cell bodies of somatic sensory neurons located in the ganglia on the dorsal roots of the upper thoracic spinal nerves and in the geniculate ganglion. The synapse relations between afferent sympathetic and afferent somatic neurons provide the mechanism for the transfer of sympathetic sensory impulses to the somatic sensory system (see page 302).

The Vasoconstrictor Center.—The vasoconstrictor center is located in the medulla oblongata (bulb) and is always in tonic activity. The cell bodies of the center give off axons which descend in the spinal cord and terminate at various levels in the ventral (motor) horn of gray matter, from the first thoracic to the second or third lumbar spinal nerves. Here they synapse with the cell bodies of the preganglionic[1] (efferent) sympathetic neurons. The cell bodies of the vasoconstrictor center with their axons form, therefore, central or intercalary neurons of the vasoconstrictor pathway.

The Vasodilator Center.—That vasodilator fibers exist for the supply of erectile tissue, glands and muscles is established beyond peradventure. These fibers are, however, not connected centrally, so far as the evidence tends to show, with a single center. Presumably the dilator fibers in the pars intermedia of the facial, the glossopharyngeal, and the cervical sympathetic have their cell bodies located variously in the medulla. Additional vasodilator centers are, doubtless, present in the spinal cord. Physiologic evidence tends to show that the vasodilator fibers are not in tonic activity as are the vasoconstrictor fibers. From the anatomic arrangement of the pale muscle fibers in the walls of blood-vessels, it would seem that the vasodilators when stimulated bring about turgescence of a vascular area (dilatation of the vessels) by inhibiting the tonic action of the vasoconstrictors.

[1] Recent experimentation seems to indicate that in the thoracic segments of the spinal cord the cell bodies of the preganglionic neurons may under some conditions function as subordinate vasoconstrictor centers capable of tonic and reflex activity.

C. Reflex Circuits

The anatomic relationships of neurons within the correlation centers mentioned in the foregoing paragraphs complete reflex circuits or arcs, composed of *receptors*, *adjustors*, and *effectors*. Moreover the circuits provide *afferent* (somatic sensory neurons of trigeminal nerve and sympathetic sensory neurons) and *efferent* (somatic motor neurons of various cranial nerves, somatic motor neurons of the upper spinal nerves, and sympathetic motor neurons of the cranial and thoracolumbar outflows) conductors or pathways, whereby the adjustors or correlation centers are brought into physiologic relations with the receptors (sense organs) and effectors (response organs). These several components of the neuron arc or circuit provide the anatomic mechanism for reflex phenomena that follow adequate stimulation of the general afferent fibers of the trigeminal nerve and seemingly of sympathetic afferent fibers that borrow the branches of the trigeminal nerve as pathways for a greater or less distance in their course to the central axis.

It is not deemed profitable nor essential in this connection to speak of the anatomic arcs for the divers simple and complex reflex acts and phenomena that take place following adequate stimulation[1] of the receptors or sense organs located within the nasal mucous membrane and related parts. A single reference will suffice to point out the general principles involved.

When, for example, the normal unanesthetized mucous membrane is stimulated with an applicator brush, or an irritant gas is inhaled, there follows immediately and before consciousness can be a factor a reflex twitching of the facial muscles, movements of the eyeball, a movement of the head to one side, and an elevation of the arm in an effort to remove the offending brush or gas. Furthermore, a careful examination will show that the blood-vascular network within the nasal mucous membrane has undergone a dilatation or turgescence, to be followed by an increased secretion of watery fluid from the glands of the mucous membrane; indicating a stimulation of the vasodilator and secretomotor centers, whereby the tonic effect of the vasoconstrictor center is reflexly inhibited. Sneezing not infrequently follows. The intensity of the reactions is in direct accord with the degree of stimulation. The reflex movements of the striped muscles of the face, neck, arm, etc., are due to the central

[1] It must be recalled that receptors respond only when the stimulus is sufficiently strong and of the proper sort—degree of intensity and kind is, therefore, the adequate stimulus. Arthur F. Hertz has shown that "a nerve-ending may be sensitive to one form of stimulation—the adequate stimulus—but insensitive to all others." The Sensibility of the Alimentary Canal, London, 1911.

connections between the somatic sensory neurons of the trigeminal nerve and the somatic motor neurons[1] of various cranial and spinal nerves. The reflex movements of these can, of course, be voluntarily inhibited, controlled or modified, since the opposite pyramidal tract (corticopontine, corticobulbar, corticospinal fibers) gives collaterals and terminals to the nuclei of the several motor cranial nerves and to the ventral (motor) horn cells of the spinal cord.

The sneezing, however, cannot be voluntarily controlled, neither can it be voluntarily performed. The afferent channels are the internal nasal branches of the trigeminus and at times the olfactory (the latter in case of intense odors). The efferent or motor paths lie in the nerves of the muscles of expiration. In the correlation center connecting neurons are interposed. While sneezing cannot be performed voluntarily, it may be inhibited by compressing the medial nasal nerve below the septum mobile nasi. Here we have the operation of antagonistic reflexes—the reflex incident to the compression of the medial nasal nerve (of the ophthalmic division of the trigeminus) overcoming or inhibiting the reflex of sneezing incident to stimulation of the nerves in the interior of the nose (of the maxillary division of the trigeminus).

Moreover, the control of the nasal congestion and glandular activity are not under the power of the will since unstriped or pale muscle and glands are involved. It is well known that the central processes of the cell bodies of the sympathetic afferent neurons synapse with either somatic or sympathetic efferent or motor neurons within the central nervous system in the completion of reflex arcs. Experimental evidence tends also to show that afferent somatic neurons, in addition to completing reflex arcs with efferent somatic neurons, participate in the formation of reflex arcs in which the efferents are of the sympathetic type. It is, therefore, possible that an impulse from the nasal cavity meant primarily to bring about reflexly a pure motor response of striated muscles results in a vasomotor phenomenon as well, *e.g.*, turgescence of the erectile tissues of the nose. It is obviously difficult to determine whether the afferent impulse from the nose reached the central nervous system by way of sympathetic sensory or somatic sensory neurons, owing to the intimate anatomic rela-

[1] The efferent neurons of the trigeminal, facial, glossopharyngeal, vagus and accessory nerves supplying striated muscles in the head and neck are often referred to as special visceral efferent (motor) neurons, since the muscles they supply are derived from the unsegmented mesoderm and not from the early mesodermal segments—the source of the somatic striated muscles. It must, however, be understood that the facial, mandibular, hyoid, laryngeal and pharyngeal muscles are striated and are under the control of the will and that their nerve endings are like those of the striated muscles of the somatic series proper.

tionships that are established, whereby transfer of sensory impulses from the sympathetic to the somatic system is continually made. However, the trigeminal nerve is obviously the important afferent pathway.

It must, however, be recalled that, even though the turgescence and depletion of the nasal mucosa is commonly a simple reflex phenomenon, under certain conditions the erectile tissue of the nose is readily influenced by psychic states, indicating a connection between the vasomotor centers and the cerebral cortex. Indeed, intracentral efferent neurons from the cortex to the vasomotor reflex centers have been demonstrated. Moreover, while it is true that the exteroceptive arcs are most closely connected with the skeletal musculature and the interoceptive with the visceral, and that seemingly some resistance to conduction from one to the other exists, the fact remains, nevertheless, that the unstriped muscle of the blood-vascular areas is readily influenced by stimulating either the interoceptive or the exteroceptive fields.[1]

Turgescence of the cavernous tissue of the nasal mucous membrane is essentially a vasodilator phenomenon, just as Eckhard has shown for the erection of the penis and clitoris, and is due either to a reflex excitation of the vasodilator centers and fibers or to a reflex inhibition of the tonic activity of the vasoconstrictor center. If the latter, one sees how the nasal mucosa would become depleted after a temporary congestion, by a removal of the inhibition and an assertion of the tonic action of the vasoconstrictor center and fibers, whereby the size of the vascular areas becomes lessened. It is obvious that psychic states play an important rôle in the stimulation of the vasodilator centers—blushing of the face from emotions, congestion of the salivary glands on thinking of an appetizing food, the erection of the cavernous tissues of the male and female genitalia in erotic states of mind are common examples.

Reflex Nasal Manifestations Incident to Nasal Disease and Disorders.—The reflex circuits or arcs provide also the anatomic and physiologic mechanisms for the many and varied reflex manifestations that are encountered clinically in diseases of the nose and paranasal (accessory) sinuses and in malpositions of nasal parts. Pure nasal neuroses are not as common as one time believed. Careful study and examination in many instances reveal the source of the reflex. It is, of course, obvious that adequate and suitable stimulation of the sense organs of the normal nasal fossæ and sinuses will, in some instances at least, result in reflex nasal manifestations not unlike those encountered in nasal disease, etc. Some of the so-called reflex nasal manifestations incident to nasal dis-

[1] Charles S. Sherrington: The Integrative Action of the Nervous System, New Haven, 1916.

orders and those of neighboring parts are in reality of a referred nature and should not be thought of as reflexes (pages 302 and 305).

Many of the reflex nasal manifestations are puzzling from an anatomico-physiological viewpoint and much work needs to be done to clear the obscure horizon. Indeed, further study may show that anatomy and physiology have no adequate explanation for some of them. However, in spite of some obscure conditions, there are many reflex and referred nasal manifestations that occur in nasal diseases that can be accounted for by the anatomic arrangements and relations of neurons composing neuron circuits, and unless these pathways are kept in mind and clearly understood faulty interpretations will be given many of these reflex and referred phenomena which emanate from the nose, the paranasal sinuses and the related parts.

It is not the province here to enter into a discussion of the many reflex nasal manifestations and neuroses. The reader is referred to treatises on clinical neurology and rhinology for detailed expositions concerning them. The reflex and referred manifestations encountered in nasal disease can in a general way be divided into motor, sensory, trophic, and vasomotor. In relation with the respiratory tract one meets with such important conditions as sneezing, coughing and asthma, which are directly traceable to nasal disorders. Reflex phenomena in the ear referable to nasal disease are not uncommon. Lacrimation due to turgescence of the inferior nasal concha has been reported. Migraine and neuralgias may be referred manifestations due to conchal lesions, sinus disease, septal spurs, etc. Gastralgia, indigestion and vomiting have been recorded as produced reflexly by intranasal disease. Alteration of the cardiac rhythm and numerous sexual phenomena frequently have a definite nasal reference. The reverse may also be true, *e.g.*, nasal phenomena have a definite sexual origin.

One naturally wonders how, for example, the cardiac rhythm can be affected by nasal disease and by suitable or adequate stimulation otherwise applied to the interior of the nose. It has been demonstrated that experimental irritation of certain portions of the nasal mucous membrane results in an alteration of the heart beat. Moreover, it has been reported that some typical cases of so-called cardiac neuroses and arhythmias were cured by the treatment of hypertrophied nasal conchæ and deflected nasal septa. It is necessary in this connection to recall (1) that afferent impulses from the nose pass over the trigeminal fibers (somatic sensory neurons) to the terminal trigeminal nucleus, thence by way of the centrally directed trigeminothalamic tract to the thalamus and from there to the

somesthetic area of the cortex for the conscious recognition of such impulses (some impulses may pass via sympathetic afferent fibers over the peripheral branches of the trigeminal, the great superficial petrosal and the pars intermedia of the facial), and (2) that nasal impulses may follow reflex axons from the nucleus of termination of the trigeminal nerve and collaterals from the trigeminothalamic tract to the dorsal nucleus of the vagus nerve (nucleus of the ala cinerea) located in the medulla and which contains the cardio-inhibitory center. In all probability connections are also established with the predominant cardio-accelerator center located in the medulla and secondary cardio-accelerator centers of the high thoracic cord.

The inhibitory preganglionic neurons (sympathetic motor) to the heart represent a component part of the outflow of the medulla or bulbar sympathetic fibers, the cell bodies of which are located, as stated above, in the dorsal nucleus of the vagus nerve, and the peripheral fibers (axons) are distributed by way of the trunk of the vagus. The peripheral fibers end by synapsing with sympathetic ganglion cells, located within or near the heart, of cardio-inhibitory postganglionic neurons destined for the supply of the heart muscle. The preganglionic accelerator neurons to the heart emerge from the spinal cord in the ventral roots of the first, second, third and fourth thoracic spinal nerves. The cardio-accelerator center, probably located in the medulla, establishes synapse relationships with the cell bodies of the preganglionic accelerator fibers located in the ventral horn of the spinal cord. It is, therefore, obvious that the heart beat which is inhibited by the bulbar sympathetic (visceral) system through the vagus nerve and accelerated by the thoracolumbar sympathetic system through certain thoracic spinal nerves, can be reflexly influenced by *adequate* afferent stimuli of nasal origin. This, since neuron pathways are provided not only for the possible conscious recognition of the sensory impulses, but also pathways whereby the somatic sensory and the sympathetic afferent impulses are carried to the correlation or adjustor centers and from there sympathetic efferent impulses to the heart muscle.

Since the nucleus ambiguus contains the cell bodies of origin of the somatic efferent or motor fibers of the vagus nerve[1] which supply the cross striated muscles of the pharynx and larynx there is a reason for the so-called nasal cough (reflex cough) in disorders of the nasal fossa, and since the opposite pyramidal tract gives terminals and collaterals to the nucleus

[1] Probably the glossopharyngeal nerve receives efferent fibers from the nucleus ambiguus. Cunningham, however, questions whether this nerve contains any motor fibers at all, there being paths by which the fibers of its so-called motor branch to the stylopharyngeus muscle might enter the nerve from sources other than the nucleus ambiguus.

ambiguus for the movements of the larynx and pharynx the cough may be voluntarily controlled unless the nasal stimulation, owing to diseased states, is excessive and the resultant reflex cough beyond the control of the will.

Most of the cerebrospinal control of the visceral reactions is effected from the sympathetic centers located in the medulla by way of the vagus nerve. Sympathetic efferent (preganglionic) fibers with cell bodies located in the dorsal nucleus of the vagus are distributed by the vagus to various sympathetic ganglia. From the latter go forth postganglionic neurons for the supply of such organs as the esophagus, the stomach, the small intestines, the lungs, the heart (inhibitory, referred to above), etc. These connections account for such reflex manifestations as asthma, gastralgia and vomiting in nasal diseases. It is well known, for example, that the removal of nasal polypi or the exenteration of the ethmoid labyrinth in severe ethmoiditis have effected cures of troublesome and vague asthmas. Moreover, the relationship between the nose and attacks of bronchial asthma has also been established experimentally. Weak electrical currents applied to the nasal mucous membrane increase the intrabronchial pressure (Lazarus).[1] Stimulation of the nasal septum produces spasm of the muscular walls of the smaller bronchioles (Brodie and Dixie).[2]

Naso-sexual Relations.—The wide connections between the cortical olfactory centers and other parts of the cerebrum provide anatomic and physiologic mechanisms for the many associations connected with odors. Moreover, it is obvious from daily observations and experiences that in many animals (man included, although to a less degree) the olfactory sense is very intimately connected with sexual reflexes.

Apart from the peripheral and central olfactory organs there appears to exist a definite physiologic and pathologic relationship between the nose and paranasal sinuses and the sexual organs. Certain sexual conditions seem to have a nasal reference and vice versa, *e.g.*, some nasal disorders seemingly are the result of sexual irritation or disease. Indeed, there are some striking anatomic and physiologic analogies between certain portions of the sexual organs and the nose. Menstrual life may be established by the occurrence of nasal bleeding. Turgescence of the erectile tissue of the nasal fossæ may regularly accompany menstruation in women with normal nasal mucous membranes. Nose-bleed is frequent in boys at the age of puberty. The symptoms of nasal diseases are not in-

[1] Deut. Med. Woch., XVII, 1891.

[2] Trans. Path. Soc., London, LIV, 1903.

frequently aggravated during the menstrual period and following sexual excesses. Indeed, sexual excesses in some instances appear to be the cause of certain nasal disorders. Moreover, reflex sneezing, engorgement of the nasal erectile tissue, coryza, hypertrophic changes in the nasal fossæ have been reported as concomitants of sexual excesses. Elsberg some years ago suggested that arrested sexual development might be due to nasal disease. Schiff stimulated the noses of female dogs and found that in 7 out of 15 animals experimented upon contractions of the uterus followed the nasal irritation. Control stimulations of the sciatic nerve gave feeble uterine responses. Priapism due to nasal disorders is not unknown, cures having followed nasal treatment. Certain dysmenorrheas are believed by some clinicians to have a definite nasal reference.

Many of the so-called naso-sexual relations are obscure. Probably some have a phylogenetic bearing. Others may be merely the expression of a more or less uniform reaction of anatomically similar tissues, *e.g.*, erectile or cavernous tissues. Pure neuroses are doubtless encountered. However, certain of the naso-sexual relations, when carefully studied, seem to be of a reflex nature with the source of the reflexes located either in the genital apparatus or in the nasal cavity. The cause of such reflexes may be due to diseased states or adequate stimuli otherwise applied. In this connection a knowledge of the established neuron arcs or circuits is essential. As stated previously, asthmas, coughs, vomiting, alterations of cardiac rhythm, etc., are frequently reflex expressions of nasal stimulation incident to disease, etc. For these manifestations the neuron pathways are more or less definite and established. It is, therefore, plausible and indeed probable that nasal stimulation if of the proper sort will reflexly influence the sexual apparatus (exclusive of the obvious influence of the olfactory sense on the sexual reflexes). Indeed, laboratory experimentation and clinical evidence lend support to the thesis. Unfortunately the neuron arcs or circuits are not as well known in this connection as elsewhere. However, some outstanding facts are unmistakable. It is obviously difficult to establish certain links in some neuron circuits (reflex circuits) and until this is done it is justifiable and proper to assume *tentatively* certain facts based on established related facts and clinical evidence and experience. One must, however, remember that some of the reported cures of reflex manifestations in patients following treatment of the nose or sexual apparatus mean nothing more nor less than suggestion and mental influence on the part of the patient and want of discriminate judgment on the part of the physician. It is not deemed profitable in this connection to discuss the many and varied observations

reported in the literature, suffice it to speak of a few conditions in which nasal irritation seemingly gives rise to reflex genital expression, with special reference to probable neuron circuits.

Priapism is according to some apparently authentic cases occasionally caused reflexly by nasal disease. The removal of the nasal irritant with a concomitant cure of the priapism seems to establish the nasal source of the reflex. In this connection one must, however, always bear in mind that intermittent priapism is not infrequently seen in neurasthenic men subjected to prolonged mental strain and that the cure of the priapism following nasal treatment may be merely a mental suggestion. In spite of the fact that in the vast majority of cases priapism is an expression of spinal lesions, etc. (see proper treatises on the subject), the nasal fossæ as a *possible* source of the reflex seems established. One naturally wonders, however, what the possible underlying anatomic and physiologic mechanism of the relationship can be. Despite the relative unimportance of this relationship, it may not be amiss to briefly survey neuron pathways and centers that may possibly be involved in this and other connections.

Persistent abnormal erection of the penis, usually without sexual desire (priapism), like the normal erection of the penis is a vasodilator phenomenon. Normal erection is a reflex act effected through a secondary center in the lumbar cord. This center may be aroused by psychic impulses descending from the brain (erotic sensations, for example) or reflexly by sensory (afferent) impulses arising in the genital tract and elsewhere. Persistent (at times intermittent) abnormal erection or priapism is likewise clearly a reflex act and doubtless effected through the same secondary erector center in the lower portion of the spinal cord. The center may be aroused by afferent impulses incident to pathologic conditions of the genital tract—for example, gonorrhea; or by afferent impulses arising from pathologic states in more remote parts of the body—for example, the nasal fossæ (priapism due to spinal cord and blood conditions do not concern us here).

The sacral efferent sympathetic fibers (preganglionic) make their exit from the spinal cord with the ventral roots of the second, third and fourth sacral nerves. These sympathetic fibers become massed in the pelvis and form the nervus erigens (pelvic nerve), which terminates about cell bodies of sympathetic ganglia located in the hypogastric or pelvic plexuses. From the cell bodies of these ganglia go forth fibers (postganglionic) for the supply of the pelvic viscera. Some of these fibers are vasodilator in function to the vessels of the pelvic organs and the external

genitalia. Stimulation of the pudendal nerve or of the nervus erigens results in a turgescence or erection of the erectile tissues of the penis, clitoris, etc.; seemingly by inhibiting the vasoconstrictor fibers which arise from the second to the fifth lumbar segments of the spinal cord and pass as preganglionic fibers to the inferior mesenteric ganglion. From the latter issue, among others, postganglionic vasoconstrictor fibers which course by way of the hypogastric (sympathetic nerve) and plexus and the pudendal nerve (internal pudic nerve) to the erectile tissues of the penis, clitoris, etc.

There is strong evidence that the dominating vasodilator center is located in the medulla with subordinate centers in the spinal cord; for example, the erection center in the lumbar region. The dominating vasodilator center is connected by descending fibers with the cell bodies of preganglionic neurons issuing from the subordinate erection center. As stated before, stimulation of the nervi erigentes leads to erection of the penis, and the erectile genital tissues of the female. Moreover, irritation of the glans penis, clitoris, etc., leads to erection even after the lumbar cord is severed from the remaining portion of the cerebrospinal axis. This indicates that the afferent impulses pass over the pudendal nerve, moreover, that the subordinate center can function independently of the dominating center. Eckhard[1] found that erection of the penis can be produced by stimulation of the spinal cord, of the medulla, and of the pons as far as the peduncles. This may explain the phenomenon of priapism in spinal cord and brain stem lesions. It has been shown also that the psychical activity of the cerebral cortex has a profound influence on the vasodilator nerves of the sexual apparatus. Indeed, Pussep[2] has shown that electrical stimulation of a definite field of the cerebral cortex leads to penile erection and ejaculation in dogs. It is, therefore, obvious that the subordinate vasodilator (erection) center in the lumbar region can be directly stimulated reflexly by irritation of the genital system. Moreover, it is equally clear that the dominant vasodilator center exercises some sort of control over the subordinate center by way of the neuron connections. Since the trigeminal nerve (carrying afferent impulses from the nose, etc.) establishes relationships through intercalated neurons with somatic and sympathetic efferent neurons (of various motor cranial nerves and of the upper spinal nerves), it is highly probable that similar relationships are established with the dominant vasodilator center probably located in the medulla. And, as stated above, the domi-

[1] Eckhard, Beiträge zur Anatomie und Physiologie, 1863 and 1869.

[2] Hermann's Jahresbericht der Physiologie, Vol. XL, 1903.

nant and subordinate vasodilator (erection) centers are connected. This would establish a complete neuron arc (or better, circuit) from the nasal cavity to the erectile tissue of the genital apparatus, thereby providing an anatomic mechanism for the causation of priapism incident to nasal disorders.

Fleiss in 1895 and 1897[1] called the attention of rhinologists and gynecologists to what he considered an important relationship between certain areas of the nasal mucous membrane and the female genitalia and adnexa. He found when applying a 20 per cent. solution of cocaine to an exceedingly small area of mucous membrane on the tuberculum septi, directly opposite the mid-portion of the middle nasal concha, and to the mucous membrane over the ventral portion of the inferior nasal concha that pains in the back and abdomen incident to dysmenorrhea ceased after five- to eight-minute applications and did not return until the effect of the drug had disappeared. Moreover, Fleiss claimed that if the anterior portion of the inferior concha on either side of the nose was touched the headache ceased, but had no effect on the abdominal pains. If one side of the nose was treated with a 20 per cent. solution of cocaine, applied to both of the spots, the headache and the pain on the opposite side of the abdomen was relieved. To obtain a definite cure of the dysmenorrhea it sufficed, according to Fleiss, to destroy the nasal areas in question with the galvano-cautery. Because of their apparent connection with the genitalia and adnexa Fleiss designated these areas of the nasal mucosa the *genital spots*.

Since the initial reports by Fleiss a number of rhinologists and gynecologists have treated dysmenorrhea with cocaine, trichloracetic acid, menthol and the actual cautery by way of the so-called genital spots, with very divergent results. Some confirm the findings of Fleiss, others find the treatment efficacious in a selected type of cases, while a third group of clinicians consider the treatment of dysmenorrhea by way of the nasal mucosa irrational, and when found "effective" to be merely the imagination of the patient and the physician.

Anatomically, as stated elsewhere, the nasal mucous membrane is divided into the olfactory and the respiratory portions, the former containing the perceptive olfactory elements. The respiratory portion over the inferior nasal concha, a goodly portion of the middle nasal concha and the adjacent portion of the nasal septum is distinctly cavernous in its structure and assumes the rôle of an erectile tissue. Further study may point to the erectile-tissue portion of the nasal mucous membrane as most

[1] Wien. Klin. Rundschau, 1895. The Relation of the Nose and Female Genitalia, Leipsig, Vienna, 1897.

intimately related with the genitalia and adnexa. This area of the nasal mucosa is, however, much more extensive than the genital spots of Fleiss. As stated on page 272, the "genital spots" do not present histologic characteristics that particularize them from the erectile-tissue portion of the nasal mucous membrane.

It would appear from various experiments and observations that the pelvic sexual organs are reflexly influenced from divers sources. The uterus, for example, contracts reflexly on stimulating the central end of the sciatic nerve (Basch and Hofmann), the central end of the brachial plexus (Schlesinger), the nose (Schiff), the nipple (Scanzoni). Linder in a number of laparotomies observed contraction of the uterus following irritation of the nasal mucosa corresponding essentially to the distribution of the nasal cavernous tissue. Spiegelberg found that stimulation of the lumbar and sacral parts of the spinal cord caused powerful uterine movements. The observation has also been made that stimulation of the sciatic nerve results in reflex stimulation of the vasoconstrictor fibers of the uterus. Now comes the contention that certain types of dysmenorrhea, doubtless meaning more than merely a uterine congestion, have a nasal reference. In general, the pelvic field is supplied by vasoconstrictor nerves by way of the hypogastric nerve and plexus (pre- and postganglionic neurons) from the last thoracic and upper lumbar segments of the cord and by vasodilator fibers through the nervi erigentes and their postganglionic connections.

Stevens in French's Index of Differential Diagnosis classes dysmenorrheas into three basic types—spasmodic, congestive and membranous—and gives a number of causes for the several types. He holds that spasmodic cases are practically always primary, that is, they commence with the onset of menstruation; while congestive and membranous types are secondary, that is, acquired as a result of some definite lesion. There is, however, no conformity in treatises on gynecology on the subject of dysmenorrhea, this applying equally to classification, etiology and treatment.

The relation of the nose to dysmenorrhea is *extremely obscure and certainly not established* at the present time despite the fact that many very suggestive clinical observations have been made. In some of the congestive types of dysmenorrhea, if there be such, nasal disease or disorders may possibly be a factor in reflexly stimulating the vasodilator centers of the genital apparatus, and at the time of menstruation (indeed, for some time before) lead to a hypercongestion of the extensive vascular network of the pelvic genitalia. It is, likewise, possible to conceive that nasal treatment might reflexly stimulate the vasoconstrictor center, thus

leading to a general lessening of the congestion by a constriction of the blood-vessels. Depletion of the congested areas would lessen the pressure on the nerves, thereby influencing the pain. Moreover, the permanent removal of the pathologic state in the nose, which reflexly resulted in pelvic congestion by inhibiting the peripheral tonic activity of the vasoconstrictor nerves, would permit the vasoconstrictor mechanism to assume its usual and normal tonic activity; whereby, owing to the reduced caliber of the blood-vessels, the amount of blood in the vascular channels would be lessened.

If the trigeminus nerve, through reflex neurons in the medulla, establishes synapse relations with the vasoconstrictor and the vasodilator centers, thereby bringing about reflex nasal phenomena, etc., one naturally wonders why adequate stimulation of the trigeminal nerve should not at times result in reflex pelvic phenomena, since the connections of the vasomotor centers in the medulla with related secondary centers in the lower portions of the spinal cord are fairly well established. The connections of the secondary vasoconstrictor centers (lumbar cord) and the vasodilator centers (sacral cord) with the intrapelvic and extrapelvic genitals are discussed elsewhere.

The Transference and Reference of Afferent (Sensory) Impulses.—The class of so-called reflex pains are, correctly speaking, transferred and referred sensations since there is no reflex action involved in the process. So far as the transference and reference of pain is concerned in which the nose, paranasal sinuses and related parts are at fault, two sets of nerves require attention: (1) the afferent nasal distribution of the trigeminal nerve and (2) the afferent nasal sympathetics.

1. One or other of the divisions of the trigeminal nerve is commonly involved in referred pain. Indeed, such pains may include the entire distribution of the nerve. In general, diffusion of pain over the sensory trigeminal system is at first confined to the division supplying the offending or diseased area, and as the pain impulse gains in severity there is an overflow and reference along the other main divisions of the nerve.

Dental caries, for example, while at first giving rise to a more or less local pain, may, if a marked case of nerve exposure and irritation exists, lead to such general reference of pain along the various branches of the trigeminal nerve that it is impossible for the patient to locate the source of the trouble. Extraction of a wrong and healthy tooth is a well-known error of commission in such cases. Pain in the ear due to a carious tooth of the mandible or lower jaw is of frequent occurrence and for its proper interpretation a knowledge of the composition and distribution of the

mandibular nerve (n. mandibularis, inferior maxillary nerve) is essential. It is of interest in this connection to note the anatomic communication between the inferior alveolar (dental) nerve and the auriculotemporal nerve. The auriculotemporal nerve of the mandibular division frequently refers a pain impulse coming over the lingual nerve of the same division to the ear and the temporal fossa. This is particularly true in ulceration and cancer of the tongue. Indeed, in the latter malady such reference of pain may precede the appreciation of local pain. Neuralgias of the maxillary nerve (n. maxillaris) are common in connection with caries of the upper teeth, maxillary sinus disease, medial and lateral nasal wall disorders.

Some of the worst supraorbital pains are due to disease of the frontal sinus and the ethmoid labyrinth and are referred along branches of the ophthalmic nerve (n. ophthalmicus).

It should also be recalled that the pars intermedia of the facial nerve contains a number of somatic sensory neurons, some of which are for general sensation and course by way of the great superficial petrosal nerve, the nerve of the pterygoid canal (Vidian nerve), the sphenopalatine ganglion and the small and middle palatine nerves to be distributed to the soft palate and adjacent portions of the pharynx. It is conceivable that these nerves (peripheral processes) with cell bodies in the geniculate ganglion in their way centrally through or around the sphenopalatine ganglion would be irritated in disease of the latter and thereby account for the referred pharyngeal pain (sore throat) in pure sphenopalative involvement.

2. Sympathetic afferent (sensory) fibers from the environs of the nose seemingly synapse, as stated elsewhere, either directly by collaterals or indirectly by intercalation of an additional neuron with the cell bodies of the somatic sensory neurons located in the ganglia of the dorsal roots of the upper thoracic spinal nerves. Similar relationships of sympathetic and somatic sensory paths are also probably established within the geniculate ganglion. Such synapse relations are well established for the dorsal ganglia of typical spinal nerves. Moreover, Herrick believes that collocations of sympathetic and somatic sensory paths similar to those in the ganglia of the dorsal roots of the spinal nerves exist within the spinal cord and brain. By such anatomic arrangement or mechanism, sympathetic sensory impulses from the nasal mucous membrane would be transferred from the sympathetic sensory system to the related somatic sensory system for sensorial (cortical) stimulation; and since the functions of the sympathetic nerves in general do not come into consciousness the

transferred sympathetic sensory impulses may be referred by the brain as pain to the peripheral field of distribution of the associated somatic nerves and thus brought into consciousness. It is well known that pathologic conditions of certain organs or areas may be accompanied not by pain at the site of the disease, but by cutaneous pain and tenderness in more remote parts of the body (Fig. 194*A*).

Indeed, such reference of pain occurs in some nasal disorders. A striking example apparently is found in an involvement of the sphenopalatine or nasal ganglion of Meckel. Sluder[1] has reported that in these cases there is pain in the root of the nose and in and about the eye, the upper jaw and teeth, sometimes the lower jaw and teeth, the mastoid region, the ear, and in severe cases pain extending to the neck, shoulder, breast, arm, forearm, hand and fingers; also a sense of sore throat on the same side. In this connection one must recall the distribution of the cranial nerves coming from the medulla and the pons and the composition and distribution of the brachial and cervical plexuses in order that transferred and referred manifestations may be properly interpreted.

It is obviously difficult to determine in disease of the sphenopalatine ganglion whether the afferent impulses to the central nervous system are by way of afferent sympathetic or afferent somatic neurons. Since the peripheral processes of both the sympathetic and somatic sensory neurons utilize the ganglion in question as a pathway, it would seem plausible that both systems of nerves must be involved and convey impulses from the diseased ganglion. *In all probability, however, most of the pains mentioned above associated with disease of the sphenopalatine* ganglion are in reality an expression of irritation of peripheral fibers of the *trigeminal nerve which pass via the ganglion in their course centrally.* Overflow of the afferent sensations would cause them to be referred along certain other peripheral trigeminal fibers and probably along other nerves with which the latter establish peripheral communications.

There are, however, according to Sluder, pains referred to regions far removed from the field of distribution of the trigeminal nerve and remote from the nasal fossæ and paranasal sinuses in some of the severer cases of sphenopalatine ganglion involvement. This would appear to indicate that both sympathetic and somatic afferents were involved in the mechanism of some of the referred pains in question.

[1] Greenfield Sluder: Further Clinical Observations on the Sphenopalatine Ganglion (Motor, Sensory, Gustatory), New York Med. Jour., 1910.

The Syndrome of the Sphenopalatine Ganglion Neurosis, Tr. Am. Laryngol. Assn., 1910.

The Sympathetic Syndrome of Sphenopalatine (Nasal) Ganglion Neurosis, Together with the Consideration of the Neuralgic Syndrome and Their Treatment, Tr. Am. Laryngol. Assn., 1915.

It is well known that sympathetic afferent neurons are among the constituents of the pars intermedia of the facial nerve. The peripheral processes of some of these follow the great superficial petrosal nerve, the nerve of the pterygoid canal (Vidian nerve) to the sphenopalatine ganglion. They pass either around or through the latter to be distributed with the ganglionic branches. Moreover, somatic afferents are likewise found in the pars intermedia, some of which follow the same course mentioned for the sympathetic afferents. In both instances the cell bodies of the neurons are located in the geniculate ganglion where synapse relations by collaterals are presumably established between the sympathetic and somatic elements. The transferred impulse may then be referred to the

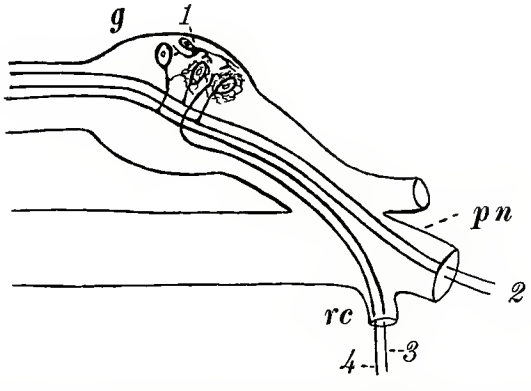

FIG. 194A.—A schematic representation of the synapse relations in a spinal ganglion whereby afferent visceral sensations are transferred from the sympathetic system to the somatic sensory system. The afferent visceral sensations do not come into consciousness as such but pass to the brain over afferent somatic paths; the brain not infreqeuntly interpreting them as pain and referring them to the peripheral field of distribution of the related somatic nerves, giving rise to referred pain.

1 = Cell of Dogiel; 2 = Afferent somatic neurons; 3 = Afferent sympathetic neuron with cell body located within the spinal ganglion; 4 = Afferent sympathetic neuron with cell body located in a sympathetic ganglion; *g*, = spinal ganglion; *pn*, = peripheral nerve; *rc*, = ramus communicans.

peripheral endings of the somatic sensory neurons by the brain and interpreted as pain. This may explain certain pharyngeal pains in involvement of the sphenopalatine ganglion (see also page 315).

It is also probable, from the clinical evidence at hand, that sympathetic afferent neurons with cell bodies located in the ganglia on the dorsal roots of the upper four thoracic spinal nerves send some of their peripheral processes (in a sense dendrites) to the nasal and adjacent fields by way of the cervical sympathetic cord, the great deep petrosal nerve, the nerve of the pterygoid canal (Vidian nerve), the sphenopalatine ganglion and its branches. In these spinal ganglia synapse relations

are presumably established between the sympathetic afferent neurons and the somatic sensory neurons, and doubtless here some transfer of sympathetic impulses is made to the somatic sensory neurons as well as some impulses carried into the cord over the axonic processes of the sympathetic cell bodies of the dorsal spinal ganglia for reflex arc connections with both sympathetic and somatic efferents (Fig. 194*A*).

Since the first and second thoracic nerves participate in the formation of the brachial plexus and the latter distributed to the shoulder, upper extremity, etc.; moreover, since sympathetic afferent impulses do not come into consciousness, save possibly in an extremely vague fashion, the brain naturally refers or interprets the sympathetic sensory impulses as pain and coming from the somatic sensory nerves of the fingers, hand, arm, shoulder, etc., to which the initial impulses from the diseased sphenopalatine ganglion have been transferred.[1]

Herrick's observation,[2] that collocations similar to those occurring in the spinal ganglia between the sympathetic and somatic sensory paths are undoubtedly established within the spinal cord and brain, probably offers the solution for referred pains in those regions where the necessary peripheral anatomic mechanisms for the transfer of sympathetic afferent impulses to the somatic afferent pathways are wanting or, if existent, are unknown.

D. The Peripheral Nerves and the Sphenopalatine Ganglion

The Maxillary Division of the Trigeminal Nerve in its Nasal Distribution.—The maxillary nerve (n. maxillaris) leaves the cranial cavity through the foramen rotundum, traverses the pterygopalatine (sphenomaxillary) fossa and enters the orbital cavity by way of the inferior orbital (sphenomaxillary) fissure. Once in the orbit the maxillary nerve is known as the infraorbital nerve and courses ventralward in the floor of the orbital cavity, traversing the infraorbital sulcus and the infraorbital canal, finally emerging on the face through the infraorbital foramen. In its course through the infraorbital sulcus and canal, the infraorbital nerve comes into intimate relationship with the roof or orbital wall of the maxillary sinus (Fig. 198). Indeed, there may be dehiscences in the caudal surface of the sulcus and the canal so that the nerve comes into actual

[1] Postscript: Since the completion of the manuscript of the foregoing discussions, Dr. Greenfield Sluder's book on "Headaches and Eye Disorders of Nasal Origin," St. Louis, 1918, has appeared. The reader is referred to this splendid work for many anatomico-clinical observations on the sphenopalatine ganglion and the paranasal sinuses.

[2] Loc. cit.

contact with the mucous membrane of the sinus for a greater or less distance.

The sphenopalatine nerves (nn. sphenopalatini) or the so-called sensory roots to the sphenopalatine ganglion of Meckel leave the maxillary nerve in the pterygopalatine fossa as two or three short, stout trunks. Contrary to what one is led to believe from a gross dissection, an exceedingly small portion of the sphenopalatine nerves enter the sphenopalatine ganglion, the larger portion passing on the lateral or ventral surface of the gang-

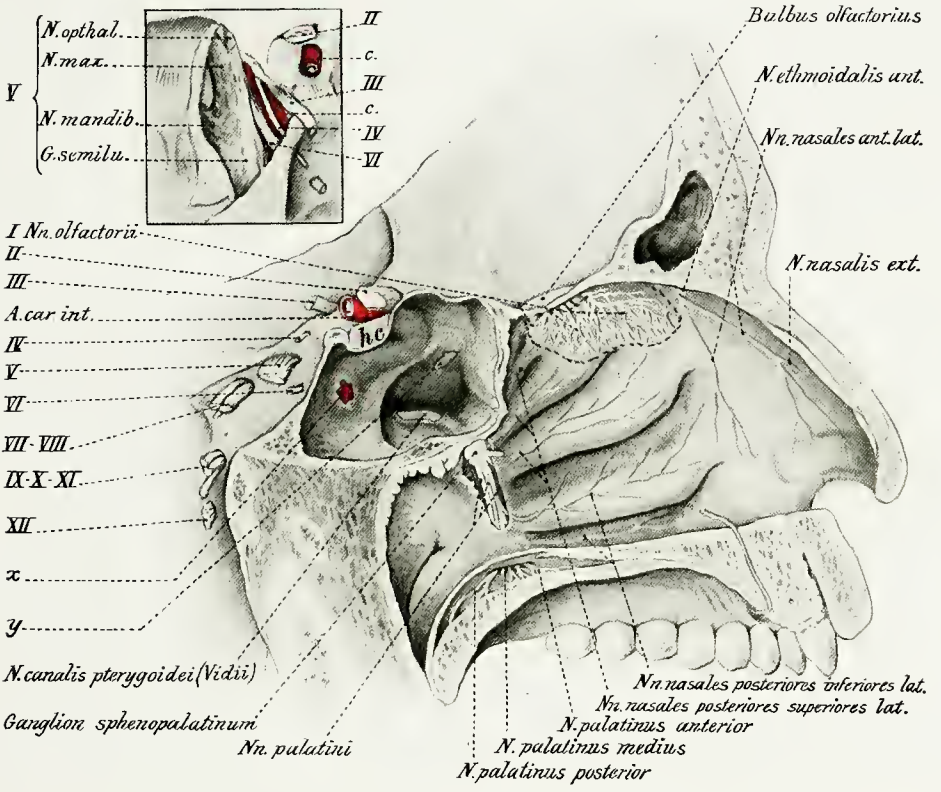

FIG. 195.—The nerves of the lateral wall of the nasal fossa. The nerves of both the olfactory and respiratory portions of the fossa are shown. Note the Vidian nerve in the floor of the sphenoidal sinus and the osseous dehiscence at *y* with exposure of the maxillary nerve to the sinus mucosa. Another osseous dehiscence at *x* exposes the internal carotid artery, which forms a serpentine-like mound on the lateral wall of the sphenoidal sinus. The inset shows the dissection of the cavernous dural sinus with contained structures.

lion to continue as the greater bulk of the fibers of the so-called branches of the ganglion. The few sensory or sphenopalatine nerve fibers that terminate in the ganglion supply the capsule of the latter and convey impulses of general sensibility from the ganglion in question to the central nervous system (Fig. 201, neuron No. 3). The bulk of the fibers that do enter and

terminate in the sphenopalatine ganglion are the axons of the preganglionic (sympathetic) neurons (motor and secretory) contributed by various nerves and which synapse with (arborize with) postganglionic (sympathetic) neurons within the ganglion, and which latter are destined for the supply of unstriped or involuntary muscle and glands located in the nose and related parts. The axons of the latter neurons, together with the sphenopalatine nerve fibers which pass on the surface of the spheno-

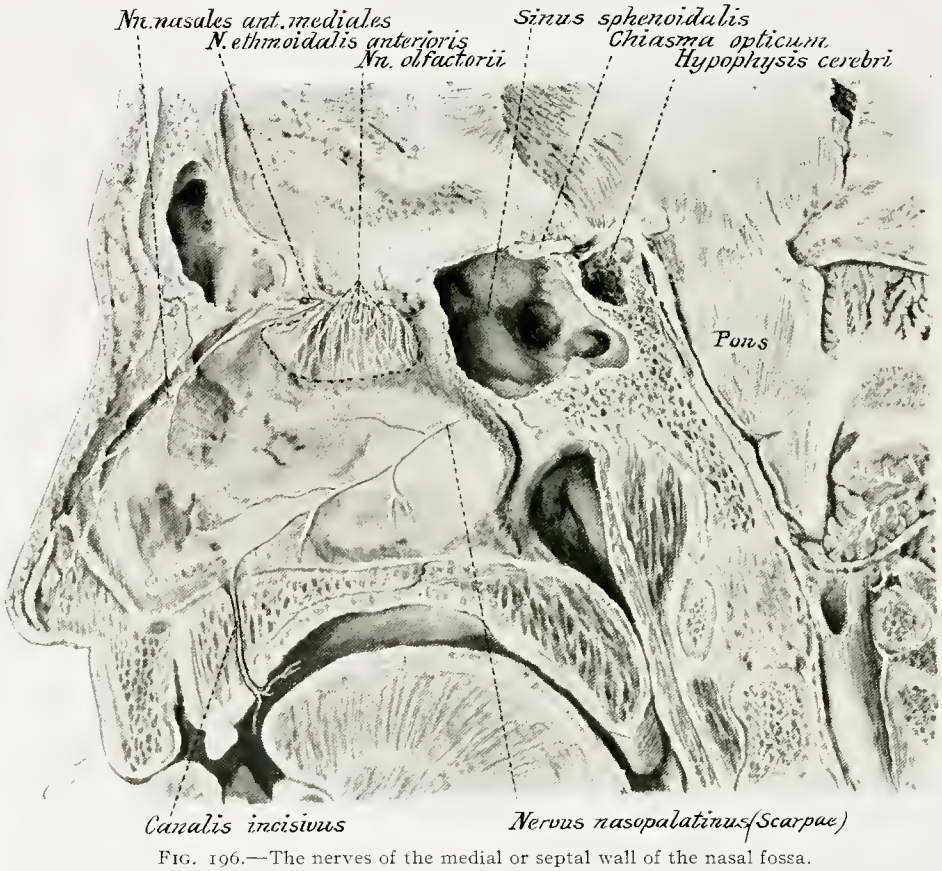

FIG. 196.—The nerves of the medial or septal wall of the nasal fossa.

palatine ganglion, conjointly form the conventional branches of the sphenopalatine ganglion; the branches containing a few fibers of cell bodies located in Meckel's ganglion and a far greater number with cell bodies located in the Gasserian ganglion. A variable number of nerve fibers whose cell bodies are located in the geniculate ganglion likewise course by way of the sphenopalatine ganglion and certain of its distributing branches. Strictly speaking, therefore, the "branches" of Meckel's

ganglion are direct continuations of the sphenopalatine branches of the maxillary nerve, augmented by a variable number of peripheral processes (axons) of postganglionic (sympathetic) neurons with cell bodies located within the sphenopalatine ganglion and of peripheral processes of afferent sympathetic and somatic neurons with cell bodies located in the geniculate ganglion, etc.

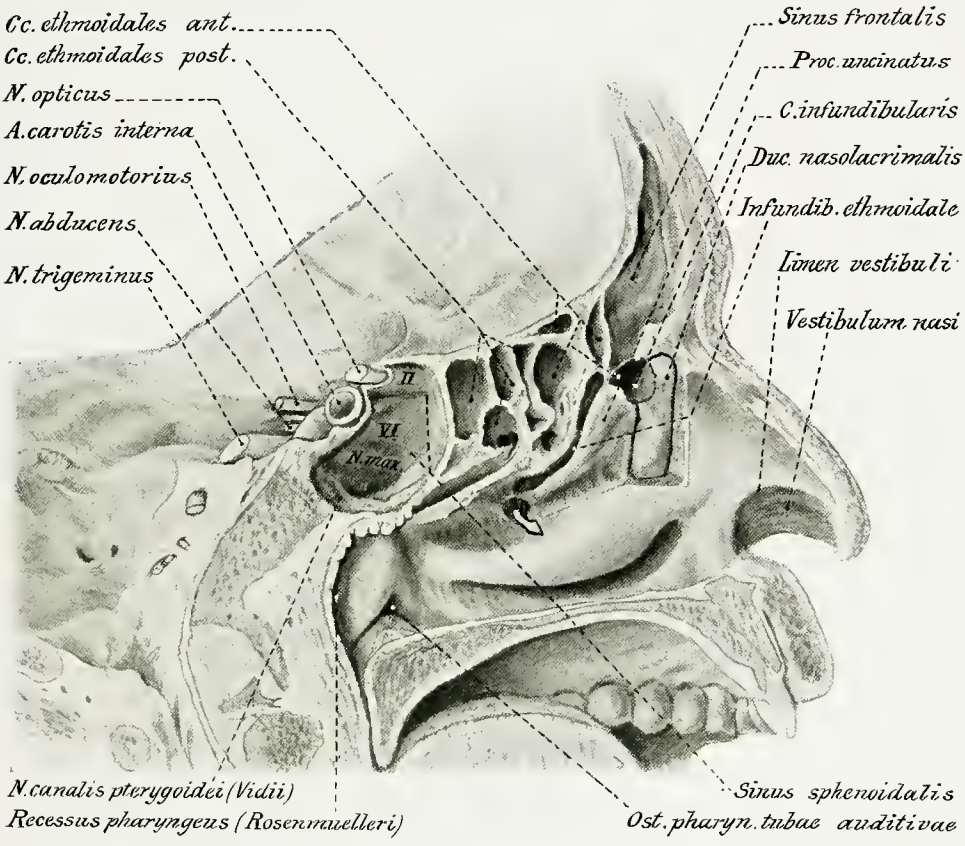

FIG. 197.—A regional dissection of a midsagittal section of an adult head. Particularly note the nerve relations of the sphenoidal sinus.

The following nerves, usually mentioned as branches of the sphenopalatine ganglion, supply both the medial and lateral walls of the nasal fossa from a line erected from the incisive foramen to the dorsal third of the cribriform plate dorsalward to the choanæ:

The orbital rami (rami orbitales) are two or three thread-like ascending branches which pass into the orbit through the inferior orbital fissure (sphenomaxillary fissure) into the orbital cavity and after traversing the posterior ethmoidal foramen, or a special foramen, are distributed to the posterior ethmoidal cells and the sphenoidal sinus.

The palatine nerves (nervi palatini) are descending branches and are usually described under three heads: (a) *The anterior palatine nerve* (nervus palatinus anterior, the large posterior palatine nerve) passes through the large posterior palatine foramen to reach the inferior surface of the hard palate, then courses forward in a groove in the hard palate and arborizes with the nasopalatine nerve (which see). Moreover, the anterior palatine nerve, in its course through the large posterior palatine foramen, gives off a variable number of posterior inferior nasal rami (rr. nasales posteriores inferiores). The latter pass through the small apertures in the perpendicular plate of the palate bone and supply the mucoperiosteum of the dorsal half of the inferior nasal concha and the adjacent portions of the middle and inferior nasal meatuses. (b) *The middle palatine nerves* (nervi palatini mediæ, the accessory posterior palatine nerves) pass through the small palatine foramen and supply the mucosa of the soft palate and the faucial tonsillar region. (c) *The posterior palatine nerve* (nervus palatinus posterior, the small posterior palatine nerve) descends in a small posterior palatine foramen to supply the inferior surface of the soft palate. Probably the facial nerve sends aberrant fibers over the posterior palatine nerve for the motor supply of the levator palati and the azygos uvulæ muscles (Fig. 95).

The posterior superior nasal rami (rami nasales posteriores superiores) are internal branches from the sphenopalatine ganglion. They pass from the pterygopalatine (sphenomaxillary) fossa through the sphenopalatine foramen into the nasal fossa. Once in the nasal fossa the filaments composing the nerves assemble themselves into two groups: (a) rami laterales, (b) rami mediales. The *lateral rami* (the posterior superior nasal nerve) supply the mucous membrane of all the structures entering into the dorsocephalic portion of the lateral wall of the nasal fossa. The *medial rami* cross the dorsal portion of the roof of the nasal fossa to reach the mucosa of the septal wall which they supply. Once in the septal mucosa the main trunk of the medial rami (nervus nasopalatinus, Scarpæ) passes ventrocaudalward in a groove in the vomer and septal cartilage to reach the Y-shaped incisive or anterior palatine foramen through which with its fellow of the opposite side it passes and forms a fine plexus. On the caudal surface the nasopalatine nerves arborize with the anterior palatine nerves (vide supra). The nasopalatine nerve and the related medial rami supply branches to the dorsal portion of the nasal roof, the nasal septum, and the portion of the hard palate derived from the palatine processes of the maxillæ (Figs. 195 and 196).

The posterior superior alveolar rami (posterior superior dental nerves), usually two, arise from the maxillary nerve before the latter be-

comes the infraorbital, pass caudally and ventrally upon the infratemporal surface of the maxilla, sooner or later entering the alveolar canals to pass to the molar teeth and to participate in the formation of the superior dental plexus. In some cases the nerves pass under cover of the mucosa of the maxillary sinus (Fig. 198).

The middle superior alveolar ramus (middle superior dental nerve) arises from the infraorbital nerve in the proximal part of the infraorbital canal. It courses caudalward in a canal in the lateral wall of the maxil-

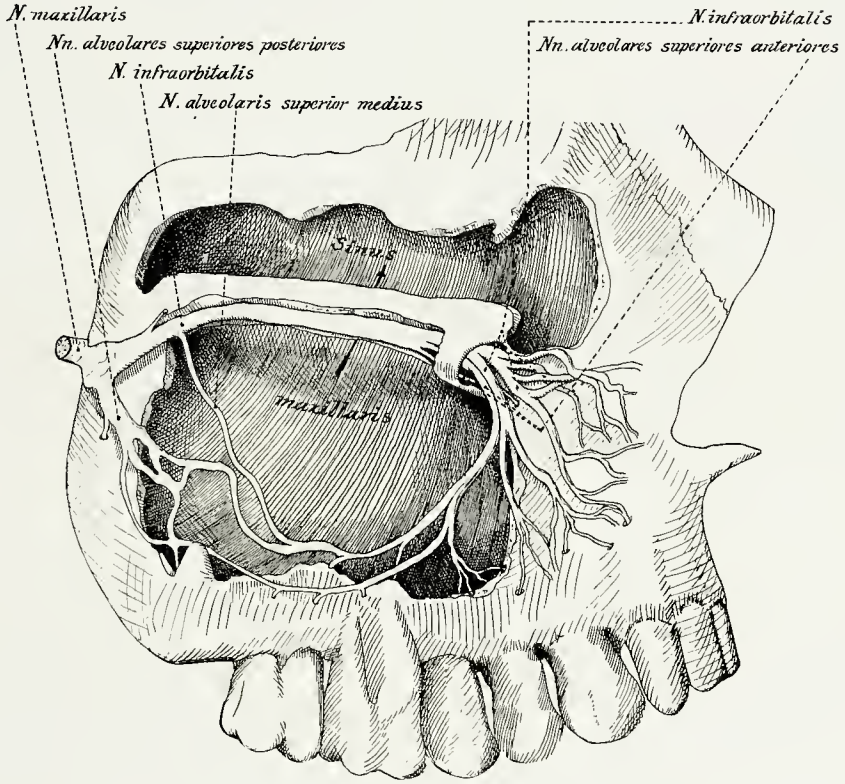

FIG. 198.—A dissection showing the maxillary and infraorbital nerves and branches as related to the maxillary sinus.

lary sinus and after entering into the formation of the superior dental plexus supplies the premolar teeth. It may arise from the anterior superior alveolar nerve (vide infra) (Fig. 198).

The anterior superior alveolar ramus (anterior superior dental nerve) arises from the infraorbital nerve immediately proximal to the infraorbital foramen. The nerve usually descends in a canal in the ventral or facial surface of the maxillary sinus. It aids in the formation of the su-

perior dental plexus and supplies the canine and incisor teeth. Occasionally the anterior superior alveolar arises from the infraorbital nerve farther dorsad than usual, passes through the caudal wall of the infraorbital canal and courses diagonally from the roof to the ventral wall of the maxillary sinus under cover of the mucous membrane. Indeed, at times the mucosa is drawn away from the bone so that the nerve is suspended by mucous membrane and in a sense is in the maxillary sinus (Figs. 198 and 199).

The anterior superior alveolar nerve gives off a *nasal branch* which enters the nasal fossa through a small canal in the lateral wall of the inferior nasal meatus to supply the mucoperiosteum of the ventral portion

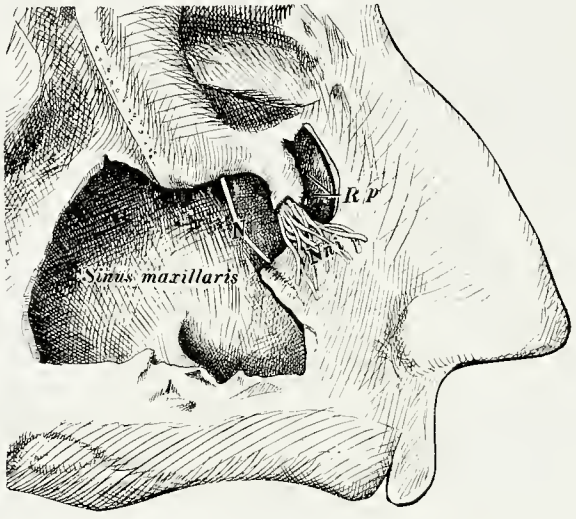

FIG. 199.—A dissection showing the anterior superior alveolar nerve (*N*) issuing from the infraorbital nerve some distance behind the infraorbital foramen and coursing under cover of the mucous membrane of the maxillary sinus (see text).

N = N. alveolar superioris anterioris; *Nni* = Nn. infraorbitales; *Rp* = Recessus prelacrimalis (sinus maxillaris).

of the under surface of the inferior concha, also the corresponding portion of the inferior meatus and the fossal floor.

The maxillary floor receives filaments from the superior alveolar (dental) nerves in their course and additional filaments from the superior dental plexus.

The infraorbital nerve after its emergence from the infraorbital canal breaks up into a large tuft-like mass of terminal branches; the *external nasal rami* (rami nasales externi), some of which supply the lateral surface of the external nose, particularly the ala nasi; and the *internal nasal rami* (rami nasales interni), some of which supply the septum mobile nasi.

The Ophthalmic Division of the Trigeminal Nerve in its Nasal Distribution.—The nasociliary (nasal) nerve, one of the three main branches of the ophthalmic nerve, originally erroneously supposed by Magendie to be the nerve of smell, but subsequently accurately interpreted by Eschricht, enters the orbit through the superior orbital (sphenoidal) fissure, between the heads of the lateral rectus muscle and between the two divisions of the oculomotor nerve. The nerve then courses obliquely across the orbital cavity to reach the anterior ethmoidal foramen located on the ventromedial surface of the orbit. The main portion of the nasociliary nerve traverses the foramen as the *anterior ethmoidal nerve* (nervus ethmoidalis anterior) and passes into the cranial cavity, then courses forward along the cranial surface of the cribriform plate of the ethmoid bone to the nasal fissure at the side of the crista galli through which it passes into the nasal fossa.

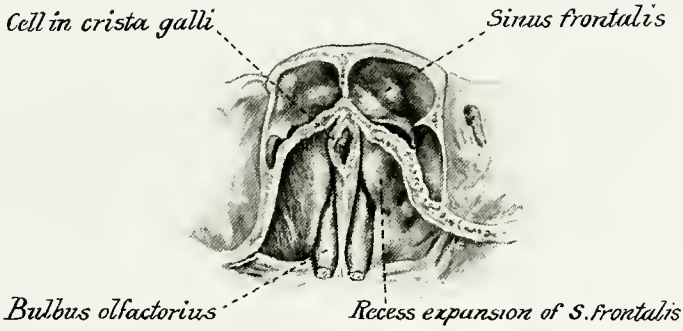

FIG. 200.—A transection through the frontal sinus and the crista galli. Note the cell in the latter and the encroachment of the frontal sinuses on the confines of the olfactory bulbs.

Before the nasociliary nerve reaches the anterior ethmoidal foramen, it frequently gives off a branch, the *posterior ethmoidal nerve*, which traverses the posterior ethmoidal foramen on the dorsomedial aspect of the orbital cavity to supply the mucous membrane of the posterior ethmoidal cells and the sphenoidal sinus. Moreover, the anterior ethmoidal nerve gives off filaments as it traverses the anterior ethmoidal foramen for the supply of the anterior ethmoidal cells and the frontal sinus. Once in the nasal fossa the anterior ethmoidal nerve terminates as such by dividing into the medial and lateral nasal branches—the *rami nasales mediales* and the *rami nasales laterales*, respectively. The *medial rami* (septal branches) supply the mucous membrane of the ventral portion of the nasal septum nearly as far as the naris. The *lateral rami* (lateral nasal nerve) are represented by two or three filaments and are distributed to the mucous membrane of the ventral portion of the lateral wall of the

nasal fossa, including the ventral portions of the middle and inferior nasal conchæ. Moreover, a branch of the lateral rami or lateral nasal nerve continues as the *ramus nasalis externus* (external nasal branch) by grooving the deep surface of the nasal bone and issuing from between the nasal bone and the lateral cartilage of the nose. It then courses caudalward under cover of the compressor naris muscle to the tip of the nose and supplies the integument over the lower half and tip of the external nose. As the nasociliary nerve nears the anterior ethmoidal foramen, it gives off the infratrochlear nerve (n. infratrochlearis) which passes forward along the medial wall of the orbital cavity below the superior oblique muscle to the medial commissure of the palpebral fissure where it ends in filaments which supply the conjunctiva, the lacrimal sac and caruncle, the integument of the upper eyelid, and the root and lateral aspect of the nose as far as the lateral nasal cartilage (Figs. 195 and 196).

The Sphenopalatine Ganglion.—The sphenopalatine ganglion (g. sphenopalatinum), also known as Meckel's, the nasal or the sphenomaxillary ganglion, is a small triangular, reddish-gray (in the fresh state) body and is a component of the group of sympathetic ganglia found in the head region of the body. It is located in the sphenopalatine fossa and very close to the sphenopalatine foramen and is suspended from the maxillary division of the trigeminal nerve. The sphenopalatine ganglion is, therefore, more or less intimately related topographically with the lateral wall of the nasal fossa, the sphenoidal sinus and certain of the posterior ethmoidal cells. In its histologic make-up it consists of an interlacement of nerve fibers and stellate nerve cell bodies. The nerve fibers, forming the ganglionic branches (see pages 306 to 311), participate in supplying the nasal fossa and the related parts.

In conformity with the other sympathetic ganglia of the head the sphenopalatine or nasal ganglion has three so-called roots which convey nerve fibers to and from the ganglion; *e.g.*, motor (visceral motor), sensory and sympathetic. Strictly speaking, it is a mere convention to designate the roots as motor, sensory and sympathetic respectively since they usually are of a mixed character as regards the physiology of their component nerve fibers. However, one or other type of fibers usually predominates in the several roots, a fact that probably justifies the naming of the roots as has been done.

The **motor root** of the sphenopalatine ganglion in its major part consists of *visceral* (sympathetic) *motor fibers* (preganglionic) of the pars intermedia of the facial nerve (n. intermedius, n. glossopalatinus). These fibers arise in the medulla oblongata from a group of cells in the reticular

formation dorsal and medial to the facial nucleus, pass through the geniculate ganglion and become component fibers of the great superficial petrosal nerve (n. petrosus superficialis major) and the nerve of the pterygoid canal (n. canalis pterygoidei Vidii, Vidian nerve) and reach their termination in the sphenopalatine ganglion by arborizing or synapsing there with the cell bodies of postganglionic neurons (see neurons numbered 6 in the diagram, Fig. 201). A few of the visceral motor fibers (preganglionic) arising within the medulla oblongata terminate within the geniculate ganglion by synapsing with the cell bodies of postganglionic neurons.

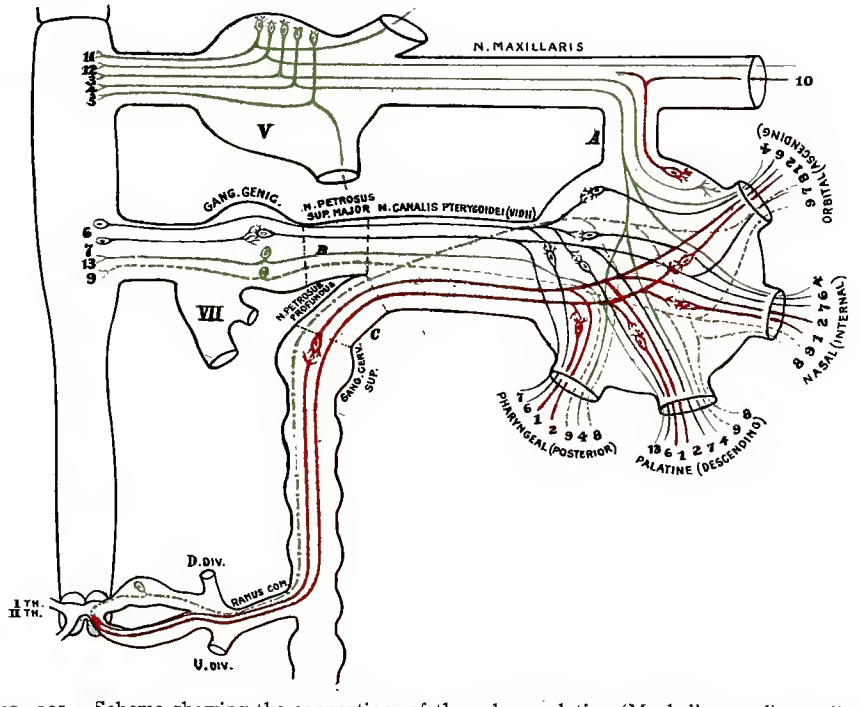

FIG. 201.—Schema showing the connections of the sphenopalatine (Meckel's, nasal) ganglion. *A* = Sensory root; *B* = Motor root; *C* = Sympathetic root. See text, pages 314 to 317, for a consideration of the component fibers of the so-called roots of the ganglion. The reference numbers are explained in the text.

The peripheral processes of some of the latter neurons follow the great superficial petrosal nerve and the nerve of the pterygoid canal of Vidian, pass through the sphenopalatine ganglion without interruption to be distributed via the ganglionic branches (see neuron numbered 7 in the diagram, Fig. 201).

It is also established that a number of *somatic sensory neurons* with cell bodies located in the geniculate ganglion are associated with or rather

are a part of the so-called motor root of the sphenopalatine ganglion. The peripheral processes of these somatic sensory neurons follow the great superficial petrosal and the Vidian nerves, pass through the sphenopalatine ganglion uninterrupted and descend in the small palatine nerve to the soft palate and adjacent parts of the pharynx where some are seemingly concerned with the gustatory function and others with general sensation. The central processes of these somatic sensory neurons terminate about cells at the upper pole of the nucleus of the alar cinerea in the medulla (see neuron numbered 13 in the diagram, Fig. 201). Moreover, there is supporting evidence that there are *sympathetic afferent neurons* associated with the motor root of the sphenopalatine ganglion. The cell bodies of these neurons are located in the geniculate ganglion, the peripheral processes of which follow the same course as the somatic sensory neurons, above referred to, save that the sympathetic afferents enjoy a wider distribution, including among other parts the nasal cavity. The central connections of the sympathetic afferents are not definitely established (see neurons numbered 9 in the diagram, Fig. 201).

The *great superficial petrosal nerve* is usually spoken of as the motor root of the sphenopalatine ganglion. It is, however, obvious from the foregoing that the nerve is not merely motor in its composition, but that in addition to the motor and most numerous fibers, it contains sensory (somatic and sympathetic) fibers. The great superficial petrosal arises from the geniculate ganglion of the pars intermedia of the facial nerve in the facial canal (canalis facialis), passes through the hiatus of the facial canal (hiatus canalis facialis, hiatus Fallopii) and a groove in the petrous portion of the temporal bone in the middle cerebral fossa. It now courses under the semilunar (Gasserian) ganglion to the position of the middle lacerated foramen (foramen lacerum) where it is joined by the *great deep petrosal* (n. petrosus profundus major) or the so-called sympathetic root of the sphenopalatine ganglion. The great superficial and the great deep petrosal nerves merge over the cephalic surface of the cartilage of the middle lacerated foramen in the formation of the *nerve of the pterygoid canal of Vidian.* The latter with accompanying blood-vessels traverses the pterygoid canal in the root of the pterygoid process of the sphenoid bone, enters the sphenopalatine (sphenomaxillary) fossa, there to connect with the sphenopalatine ganglion located on the lateral side of the sphenopalatine foramen (Fig. 145).

The **sympathetic root** of the sphenopalatine ganglion is the great deep petrosal nerve (n. petrosus profundus major) which is, in a sense, a direct extension of the carotid plexus. Indeed, the great deep petrosal nerve

may be considered the connecting or association fasciculus between the superior cervical sympathetic ganglion and the sphenopalatine sympathetic ganglion. Most of its fibers are the peripheral processes (axons) of postganglionic neurons arising from cell bodies located in the superior cervical sympathetic ganglion. These postganglionic fibers pass through the sphenopalatine ganglion uninterrupted for distribution by way of the ganglionic branches (see neurons numbered 2 in the diagram, Fig. 201). Moreover, a few of the fibers contained in the great deep petrosal nerve are seemingly the peripheral processes of preganglionic neurons arising from cell bodies located in the ventral horns of the upper thoracic spinal cord segments. These preganglionic fibers end in arborizations or synapses around the stellate cell bodies of postganglionic neurons located in the sphenopalatine ganglion (see neurons numbered 1 in the diagram, Fig. 201). In addition to the motor elements the great deep petrosal nerve apparently contains sympathetic afferent fibers, the cell bodies of which are located in the ganglia of the dorsal roots of the upper thoracic spinal nerves. Further study is necessary to definitely establish these afferent sympathetic elements. Certain laboratory experiences and clinical evidence tend to support the existence of sympathetic afferent elements in the great deep petrosal nerve (see neurons numbered 8 in the diagram).

The **sensory root** of the sphenopalatine ganglion consists of the sphenopalatine nerve or nerves, *e.g.*, of two to three short, stout trunks connecting the maxillary nerve with the upper border of the ganglion (see page 307). Most of the component fibers of the sensory root are peripheral processes or dendrites of cell bodies located within the semilunar (Gasserian) ganglion of the trigeminal nerve. A few of these sensory fibers end in the sphenopalatine ganglion for the supply of the capsule of the ganglion and the capsules of its contained cell bodies (see neuron numbered 3 in the diagram, Fig. 201). However, the vast majority of the fibers of the sensory root pass either around or through the sphenopalatine ganglion without interruption in synapses to be distributed by way of the numerous ganglionic branches (see neurons numbered 4 in the diagram, Fig. 201).

There is some evidence that a few axons of postganglionic neurons (motor sympathetic) with cell bodies located within the sphenopalatine ganglion pass by way of the sensory root to be distributed with the somatic sensory fibers of the maxillary nerve (see neuron numbered 10 in diagram).

The branches of the sphenopalatine ganglion are (1) orbital (ascending), (2) palatine (descending), (3) pharyngeal (dorsal), and (4) nasal (medial). In accordance with the foregoing paragraphs they contain

vasomotor, secretory[1] and sensory fibers. The reader is referred to pages 306 to 310 for a discussion of the ganglionic branches in their distribution to the nasal fossa, the paranasal chambers, etc.

The Anatomic Relations of the Sphenopalatine Ganglion.—The small flattened triangular body of the sphenopalatine or nasal ganglion measures from 5 to 8 mm. in its sagittal plane and has its apex directed dorsally. It occupies a relatively deep position in the pterygopalatine or sphenomaxillary fossa, just caudal to the maxillary nerve and in advance of the ventral extremity of the pterygoid (Vidian) canal and in close proximity to the lateral side of the sphenopalatine foramen.

In order that one may more fully appreciate the position and relations of the sphenopalatine ganglion, it is deemed advisable that the *pterygopalatine* (sphenomaxillary) *fossa* be briefly considered. This fossa represents in form a small inverted pyramid located at the point of juncture of the inferior orbital (sphenomaxillary) with the pterygopalatine (pterygomaxillary) fissures somewhat caudal to the apex of the orbit. The fossa is bounded *ventrally* by the infratemporal surface of the maxilla; *dorsally* by the base of the pterygoid process and the ventral surface of the great wing of the sphenoid; *medially* by the perpendicular plate of the palate bone with its orbital and sphenoidal processes; and *cephalically* by the caudal surface of the body of the sphenoid bone. Three important fissures terminate in the pterygopalatine fossa; *e.g.*, the superior orbital, the pterygopalatine and the inferior orbital; leading thereby to a connection with the cranial cavity, the infratemporal fossa and the orbital cavity, respectively. In the articulation of the palate bone with the sphenoid, the sphenopalatine notch of the former, forms with the sphenoid bone a window or aperture, the *sphenopalatine foramen*, communicating between the pterygopalatine and the nasal fossæ immediately dorsal to the superior nasal meatus and caudal to the body of the sphenoid. Six foramina communicate with the pterygopalatine fossa: one, the *sphenopalatine*, on the medial wall; three, the *foramen rotundum*, the *pterygoid* (Vidian) *canal* and the *pharyngeal* (pterygopalatine) *canal*, on the dorsal wall; one, the orifice of the *infraorbital canal*, on the ventral wall; and caudally the apex of the pterygopalatine fossa narrows into and continues as the *pterygopalatine* (posterior palatine) *canal* and the *accessory palatine canals*.

When one recalls the structures that either enter or are wholly

[1] Prevost found that feeble electrical stimulation of the exposed sphenopalatine ganglion caused a copious secretion of mucus in the nasal fossa. Moreover, an increase in the nasal temperature and dilatation of the blood-vessels was noted.

located within the pterygopalatine fossa, such as the maxillary nerve, the Vidian nerve, the sphenopalatine ganglion with its outflowing branches, etc.; moreover, that the sphenoidal and posterior ethmoidal air cells very commonly encroach to a marked degree upon the confines of the pterygopalatine fossa and secondarily upon the contained structures, one at once appreciates the importance of a clear understanding of the anatomic relationships, *e.g.*, the topographic anatomy, of the region of the pterygopalatine fossa in dealing with nasal and paranasal disorders.

Owing to the position of the sphenopalatine ganglion in the sphenopalatine fossa in close proximity to the sphenopalatine foramen, it is subject to surface influences from both the nasal fossa and certain paranasal (accessory) sinuses. The nasal mucous membrane and a variable but small amount of areolar tissue alone intervene between the ganglion and the nasal cavity in the recent or undissected state. The intimacy of the relationship between the ganglion and the nasal mucosa varies to a limited degree in different individuals. Moreover, the size of the sphenopalatine foramen is variable and when unduly large increased mucosal relations necessarily obtain. The extreme pneumatizations of the sphenoidal and posterior ethmoidal cells commonly encountered lead to additional intimate and important relations between the respiratory mucous membrane and the sphenopalatine ganglion. A lamina of bone of papery delicacy and mucous membrane not infrequently alone intervene between the outside air and the ganglion. Indeed, the bone may be actually wanting, *e.g.*, dehiscences may be present, thereby bringing the ganglion into intimate relationship or actual contact with the mucous membrane of the paranasal sinuses in question. It is particularly in those cases in which the sphenoidal sinus extends ventrocaudally recess-like into the pterygoid process (base and laminæ) of the sphenoid and into the orbital process of the palate bone and occasionally into the ethmoid bone by encroachment on posterior ethmoidal cells or by replacing them that the very intimate ganglionic relationships are established. The intimacy of the relationship is, of course, dependent upon the direction and degree of the pneumatization (Figs. 145 and 139). At times a posterior ethmoidal cell (or cells) replaces the extension of the sphenoidal sinus into the orbital process of the palate bone. Indeed, ethmoidal extensions may take place into the sphenoid bone, even pneumatizing into the root of the pterygoid process. In such cases the sphenopalatine ganglion bears a much more intimate relationship to the posterior ethmoidal cell or cells than it does to the sphenoidal sinus.

Witness, for example, the dissection represented in Fig. 135. Here

the sphenoidal sinus on the right side of the body shows extensive pneumatization extending to the left beyond the mid-sagittal plane at the expense of its fellow. The right sinus has pneumatized into the basilar process of the occipital bone, the pterygoid process of the sphenoid bone, the orbital process of the palate bone, and has actually extended forward into the dorsal extremity of the ethmoid bone. The sphenoidal extension into the orbital process of the palate bone (the palatine recess of the sphenoidal sinus) is separated from the dorsocephalic extension of the maxillary sinus by a mere film of bone. A large posterior ethmoidal cell has likewise pneumatized into the orbital process of the palate bone and is throughout separated from the sphenoidal sinus by an extremely thin lamella of bone. It is obvious in such specimens that involvement of the sphenoidal sinus or of the posterior ethmoidal cell may readily influence the maxillary sinus and vice versa. Moreover, these several sinuses, due to the extreme pneumatization, establish the most intimate relationship with the sphenopalatine foramen and the sphenopalatine ganglion. Sometimes posterior ethmoidal cells are superimposed, one over the other; the more caudally placed of which is the more intimately related to the sphenopalatine ganglion. Again, a posterior ethmoidal cell may extend its pneumatization into the body of the sphenoid bone and replace the ventrosuperior portion of the sphenoidal sinus. This does, however, not preclude the extension of the sphenoidal sinus into the root of the pterygoid process and its encroachment upon the pterygopalatine fossa with its contained sphenopalatine ganglion (Fig. 155).

Anatomical Relations of the Nerve of the Pterygoid Canal.—In a study dating from 1907[1] the author has had opportunity to observe the relations of the nerve of the pterygoid canal (Vidian nerve) in an extremely large number of cadavers. These observations were made in regular dissections and in sections through the various planes and at different ages. In many of the specimens studied the floor of the sphenoidal sinus is separated from the pterygoid (Vidian canal) by a fairly thick layer of compact bone. However, there are a large percentage of specimens in which the sphenoidal sinus extends its pneumatization caudally and ventrally into the root of the pterygoid process (Fig. 139). Indeed, the extension may pass beyond this, either medially or laterally or both, into the plates of the pterygoid process. In such instances the pterygoid canal with its contained Vidian nerve and vessels is at best merely separated from the mucous membrane of the sphenoidal sinus by an extremely

[1] The first reference by the author concerning these observations was made at an Anatomical Seminar at Cornell University in 1909.

delicate layer of bone. *Indeed, in the majority of such cases the canal is thrown into marked relief in the floor of the sphenoidal sinus so that it forms a distinct watershed dividing a lateral from a medial pterygoid diverticulum or recess of the sphenoidal sinus.* Again, it is not an unusual condition to find pterygoid canals in which the thin layer of bone is actually wanting (dehiscences), thereby exposing the contained Vidian nerve and accompanying blood-vessels to the influences of the outside atmosphere or of an infected sphenoidal sinus. The mucous membrane of the sphenoidal sinus alone is interposed between the sinus cavity and the Vidian nerve, etc. Witness, for example, Figs. 133, 139, 195 and 197 in which the nerve of the pterygoid canal courses across the cavity of the sphenoidal sinus at a considerable distance above the sinus floor proper, thereby throwing the mucous membrane into marked relief.[1]

[1] See also Greenfield Sluder, Archiv. f. Laryngol. u. Rhin., Bd. 27, Heft. 3, 1913; Annals Otol., Rhin. and Laryngol., 1913, 1914, and Ladislaus Onodi, Jour. Laryng., Rhin. and Otol., 1914, for instructive and valuable anatomico-clinical considerations of the Vidian and other nerves.

XI—THE OLFACTORY APPARATUS PROPER

CHAPTER XI

THE OLFACTORY APPARATUS PROPER

The olfactory apparatus proper may, for convenience of description, be divided into a *central organ* and a *peripheral organ*, the former extranasal in position and the latter intranasal. The peripheral organ especially concerns us in this work and some phases of its anatomy were previously considered in connection with the nasal mucous membrane. The central organ will be but briefly alluded to, and it will suffice in subsequent paragraphs to point out the general features of the olfactory brain and to refer to the more important pathways involved in olfactory reflexes and those which serve in carrying afferent olfactory impulses to the cerebral cortex and efferent voluntary impulses of cortical origin in which the olfactory element predominates.

A. The Peripheral Organ

The peripheral organ of smell in adult man is the specific sensory epithelium within the nasal fossæ—the extent of which was discussed previously under the caption "nasal mucous membrane." The perceptive elements (the olfactory receptors, the olfactory cells) of the nasal mucosa are bipolar, with short peripheral and long central processes—the latter the olfactory nerves. The peripheral olfactory tract extends from the olfactory portion of the nasal mucous membrane to the intracranial olfactory bulb, and its elements are neurons of the first order. The impulse is conducted by the peripheral processes (dendrites) to the bipolar cell bodies, thence by the central processes (axons) to the olfactory bulb.

In some of the lower vertebrates, and in mammals with a highly developed sense of smell, three nerves are apparently concerned with the peripheral olfactory organ: (1) the olfactory nerve proper, (2) the terminal nerve, and (3) the vomeronasal nerve. In man the latter is absent owing to the rudimentary state of the vomeronasal organ of Jacobson. Moreover, the terminal may not be a special sense nerve, but prove to consist of postganglionic neurons, with cell bodies located in the terminal ganglion for the supply of unstriped muscle and glands (motor and secretory), thus conforming to the postganglionic fibers distributed to the nasal

cavity, *e.g.*, the fibers from the sphenopalatine ganglion (Meckel's), etc. (see page 306).

The Olfactory Nerve (Nervus olfactorius).—In man approximately twenty non-medullated olfactory nerve filaments (the axons or central processes of the bipolar olfactory cells) issue from the olfactory mucosa near the lamina cribrosa of the ethmoid bone. These filaments (*the olfactory nerves*, collectively the olfactory nerve) pass at once through the foramina of the cribriform lamina in two rows, medial and lateral. After entering the anterior cerebral fossa the olfactory filaments pierce the cerebral meninges and enter the olfactory bulb, there to synapse with the dendrites of the mitral cells in formations known as the olfactory glomeruli. The latter contain the first synapse in the olfactory pathway (Fig. 202).

Since the days of Scarpa anatomists considered the olfactory nerves as forming a plexus in their passage from the olfactory cells to the olfactory bulb. Figures from the writings of Scarpa and Leveille, the latter doubtless influenced by the former, were frequently copied into text-books. Even to-day new books appear with adaptations from the illustrations of the above authors. However, the researches of Miss Read[1] show that, instead of a plexiform arrangement, the olfactory nerves "extend in non-anastomosing bundles to the olfactory bulb; all appearance of anastomosis being due (a) to a crossing of the bundle of nerves or (b) to a net-like arrangement of the connective tissue or blood-vessels."

The Terminal Nerve (Nervus terminalis).—The terminal nerve is a slender and variably plexiform nerve. It contains both medullated and non-medullated fibers (the latter predominate), and unlike the olfactory and vomeronasal nerves is ganglionated.

The terminal nerve is found in many classes of vertebrates from fishes to man. In man it has been satisfactorily demonstrated in fetuses and infants. The author has dissected the nerve in a number of infants. Herrick states that the nerve is present also in the adult. Its peripheral twigs are found distributed to the mucous membrane of the nasal septum and to the mucosa joining the olfactory region proper. Furthermore, it has been shown that the terminal nerve accompanies and shares the distribution of the vomeronasal nerve when the latter is present. The exact ending of the peripheral twigs of the terminal nerve is unknown. Centrally the nerve passes through the cribriform plate of the ethmoid bone in company with the olfactory nerve (or nerves) in the form of two or three small roots mesial to the vomeronasal nerve. The roots of the terminal nerve pass over the inferior mesial aspect of the olfactory bulb, here leave

[1] The American Journal of Anatomy, Vol. 8, 1908.

the olfactory fibers, continue dorsally to enter the brain in the region of the olfactory trigone.

The function of the terminal nerve is obscure. It may contain both afferent and efferent fibers (Johnson). It is well known that groups of ganglion cells are found along the extra- and intracranial courses of the nerve. Some describe the ganglion cells and the fibers as having the characteristics of the sympathetic neurons. Hardesty suggests that, instead of being an independent nerve as now claimed, the nervus terminalis may be a part of the forward extension of the cephalic sympathetic and that its neurons receive and convey impulses to the gland cells of the nasal mucosa and to the unstriped muscles of the blood-vessels of the nasal mucosa and those supplying the inferomesial part of the frontal end of the cerebrum. Others believe that the fibers of the terminal nerve may be followed through the length of the olfactory area and hypothalamus, admitting ignorance, however, of the exact cerebral connection. Herrick states:[1] "The problem of the functional and morphological relationships of the nervus terminalis must be solved before a complete understanding of the olfactory nerve itself is possible. It may be that the nervus terminalis is a remnant of a nerve of general chemical sensibility of the nose region which has been largely supplanted by the more highly developed chemical receptors of the specific olfactory system. On the other hand, it may be a nerve of general visceral efferent type, the cells of the ganglion terminale being postganglionic sympathetic neurons."

Brookover,[2] in a discussion of "the peripheral distribution of the nervus terminalis in an infant," summarizes briefly by saying that the peripheral nervus terminalis is so large in man that it may be said to be hypertrophied as compared to the known development in other mammals, without especially increasing its central root. In addition to many cells in the ganglion terminale, it contains about fifteen hundred cells peripherally under the nasal mucosa. Though disposed in three or four chief rami emerging from the lamina cribrosa, there is a vast network of interlacing bundles deep to the main arteries. Some of the fibers trail over the walls of the arteries, but the method of treatment by the silver technic does not reveal ultimate endings.

The Vomeronasal Nerve (Nervus vomeronasalis).—The vomeronasal nerve is composed of central processes of nerve cells located in the mucosa of the vomeronasal organ (of Jacobson). Since the latter is rudimentary and probably functionless as an olfactory organ in adult man, the vomero-

[1] Introduction to Neurology, Philadelphia, 1916.

[2] The Journal of Comparative Neurology, Vol. 28, 1917.

nasal nerve is absent. In those forms in which the vomeronasal organ functions in olfaction, *e.g.*, in the dog, cat, rabbit, etc., the vomeronasal nerve passes into the submucosa and joins the filaments of the olfactory nerve proper. The nerve fibers terminate in the accessory olfactory bulb on the posteromedian aspect of the olfactory bulb proper. In amphibia the vomeronasal organ is supplied by fibers from the vomeronasal, terminal and olfactory nerves. Read[1] has also shown that in man a branch of the olfactory nerve passes to the vomeronasal organ, at least at the time of birth. Some would consider the vomeronasal nerve as a special slip of the olfactory nerve and as terminating in a specially differentiated portion of the olfactory bulb—the formatio vomeronasalis of McCotter. In adult man the vomeronasal region seems to be for general sensation only and is, therefore, supplied by the trigeminus nerve and by the cephalic sympathetic fibers common to the mucosa of the general nasal fossa.

B. The Central Organ

The olfactory region of the telencephalon or end brain is usually referred to as the rhinencephalon, a term of doubtful utility owing to its varied application by anatomists. It is a well established fact that the olfactory brain is phylogenetically the oldest part of the cerebral hemisphere and that it is early differentiated ontogenetically. Owing to the fact that it is the oldest part of the cerebral hemisphere in vertebrate evolution, it is often termed the archipallium as distinguished from the greater portion of the remainder of the hemisphere—the neopallium (the corpus striatum is not a portion of the latter).

The rhinencephalon is reduced to a comparatively rudimentary state in man and primates generally, being greatly overshadowed by the non-olfactory portion of the cerebral hemisphere. This reduction is, doubtless, due to the relatively feeble olfactory sense in these forms. The archipallium reaches its highest development in the lowest mammals and the neopallium attains its maximum size in man.

The Olfactory Brain.—The por ions of the human brain connected with the olfactory apparatus may be said to include the very rudimentary olfactory lobe, the hippocampus and the uncus and certain accessory parts. These structures are either wholly or partly associated with the function of smell. From the viewpoint of morphology the olfactory brain or rhinencephalon may be divided into an *anterior* and a *posterior division.* The former consists of the several portions of the olfactory lobe and the latter of certain other parts (Fig 203):

[1] The American Journal of Anatomy, Vol. 8, 1908.

Olfactory Lobe	(*a*) Olfactory bulb (*b*) Olfactory tract (*c*) Olfactory trigone (*d*) Anterior perforated substance (*e*) Parolfactory area (of Broca) (*f*) Subcallosal gyrus (peduncle of corpus callosum)
Olfactory Cortex and Accessory Parts	(*a*) Uncus (gyrus uncinatus) (*b*) Hippocampus (hippocampus major) (*c*) Amygdaloid nucleus (*d*) Supracallosal gyrus, including the medial and lateral striæ (gyrus epicallosus, indusium griseum) (*e*) Dentate fascia (gyrus dentatus) (*f*) Septum lucidum (septum pellucidum) (*g*) Fornix (*h*) Fimbria (*i*) Mammillary body (*j*) Habenular nucleus (*k*) Thalamus (optic thalamus) (*l*) Anterior cerebral commissure (*m*) Medullary stria of thalamus (*n*) Mammillo-thalamic fasciculus (*o*) Mammillo-peduncular fasciculus (*p*) Terminal stria of thalamus (tænia semicircularis) (*q*) Habenulo-peduncular fasciculus (*r*) Etc.

The *hippocampus* (the curved eminence which extends throughout the floor of the inferior cornu of the lateral ventricle) and the uncus, while chiefly functioning as the olfactory cortex, give off many association pathways for connection with other parts of the cerebral cortex. The *hippocampal gyrus* and the *callosal* (cingulate) gyrus, collectively the *gyrus fornicatus* or the *limbic lobe* of Broca, are not here considered parts of the rhinencephalon. Broca, on the contrary, associated the limbic lobe with the center for olfaction. However, a comparatively small part of his limbic lobe appears to be specially olfactory in function. Although in superficial continuity with the hippocampal gyrus, Turner and Elliot Smith have shown that the uncus forms morphologically a part of the rhinencephalon and not of the limbic lobe as frequently stated. Histological evidence also tends to indicate that the chief cortical termination of the olfactory paths is located in the uncus and the hippocampus. Moreover, Ferrier finds that electrical stimulation in this region is followed by tortion of the lips and nostrils of the same side; muscular movements that accompany strong olfactory excitations. Ablations of the uncal region are followed by defects in the sense of smell.

The accessory parts of the rhinencephalon particularly serve in a collective sense as pathways by which olfactory cortical centers are connected with each other, on the one hand, and with the thalamus (optic

thalamus), etc., on the other. Furthermore, these pathways serve to connect the cortical centers with lower levels of the brain. The olfactory cerebral centers fall into two groups, *e.g.*, the olfactory cerebral cortex and the reflex centers of the brain stem. Olfactory impulses destined for the cerebral cortex follow different pathways from those involved in olfactory reflexes.

The olfactory bulb (bulbus olfactorius) and **tract** (tractus olfactorius) are located on the inferior or orbital surface of the brain and constitute a goodly portion of the cerebral hemisphere with extension of the ventricular cavity in many vertebrates; for example, the horse. In man, on the contrary, the ventricular (lateral ventricle) prolongation, while present at first, gradually becomes obliterated and filled in by the central neuroglia of the olfactory bulb and tract and the whole olfactory lobe reduced to a rudimentary state. The neuroglia core is demonstrable in sections of the adult bulb and tract as a gelatinous substance.

The olfactory bulb is an elongated, oval body of gray matter resting upon the lamina cribrosa of the ethmoid bone. It is essentially free save that the filaments of non-medullated axons of the olfactory nerve enter its ventral surface. Its confines are at times encroached upon by recess extensions of the frontal sinuses; moreover, a cell in the crista galli may impinge upon it (Fig. 200).

A number of strata may be distinguished surrounding the central core of the olfactory bulb: (a) the superficial non-medullated nerve-fiber layer which rests on the cribriform plate of the ethmoid, the fibers being the axons of the bipolar olfactory cells of the olfactory nasal mucous membrane; (b) the layer of the olfactory glomeruli; (c) the superficial plexiform layer; (d) the stratum of mitral cells; (e) the deep plexiform layer; (f) the granule layer; and (g) the layer of deep nerve fibers, composed of both afferent and efferent elements. As stated elsewhere, the central cavity (*ventriculus bulbi olfactorii*) is obliterated in man and filled by a modified neuroglia.

The *olfactory tract* is a narrow, more or less triangular band of white substance which arises in the olfactory bulb and courses dorsalward for a distance of from 18 to 20 mm. to the anterior perforated space where it undergoes a flattening and widening. Despite the rudimentary nature of the olfactory tract in man three strata can be demonstrated: (a) a longitudinally directed stratum of nerve fibers; (b) a modified neurogliar or gelatinous stratum, occupying the former ventriculus tracti olfactorii; and (c) a dorsal stratum of gray substance, in reality a remnant of the cortical gray matter from which fibers pass to other parts.

The olfactory tract ends as such in the neighborhood of the olfactory trigone (vide infra) by dividing into the *olfactory striæ* or *gyri:* (a) the medial stria, (b) the lateral stria, and (c) the less definite intermediate stria. The *lateral stria* courses across the lateral portion of the anterior perforated substance and bends sharply medialward to enter the uncus. A few of the fibers of the lateral stria penetrate the olfactory trigone and equally few terminate in the anterior perforated substance. The *medial stria* bends medialward and its fibers terminate largely in the parolfactory area of Broca; relatively few terminate in the subcallosal gyrus and the anterior perforated space and adjacent parts of the septum pellucidum. Some of the fibers of the medial stria form the *pars olfactoria* of the anterior commissure which connects the olfactory bulbs of the two sides. The *intermediate stria* is but little elevated above the surface, indeed not infrequently is scarcely visible to the naked eye. Its fibers terminate for the most part in the anterior perforated space; a few pass beyond to the uncus.

The further connections of the fibers of the olfactory striæ will be discussed subsequently.

The olfactory trigone or **tubercle** (trigonum olfactorium) is a small elevated triangular area immediately ventral to the anterior perforated space with its apex directed forward and projecting slightly into the dorsal extremity of the olfactory sulcus. The olfactory tract in a sense merges with the olfactory triangle, however, few of its component fibers actually terminate about cell bodies within the substance of the triangle.

The *anterior perforated substance* (substantia perforata anterior) comprises the basal region limited by the optic chiasma and tract and the olfactory trigone and in large part belongs to the rhinencephalon. The fissura prima separates the olfactory trigone from the anterior perforated substance. Ventrally and medially the anterior perforated substance is confluent with the subcallosal gyrus, and laterally is found the lateral olfactory stria on its way into the uncus and the limen insula. Moreover, the gray matter of the anterior perforated substance is confluent with the corpus striatum. Numerous blood vessesls enter the substance giving it the perforated appearance. Some fibers from the olfactory tract end about cell bodies located within the anterior perforated substance (vide supra).

The parolfactory area of Broca (area parolfactoria) is particularly related to the medial stria of the olfactory tract, since many of the latter fibers terminate in it. It is a small, more or less triangular field located on the medial surface of the cerebral hemisphere immediately

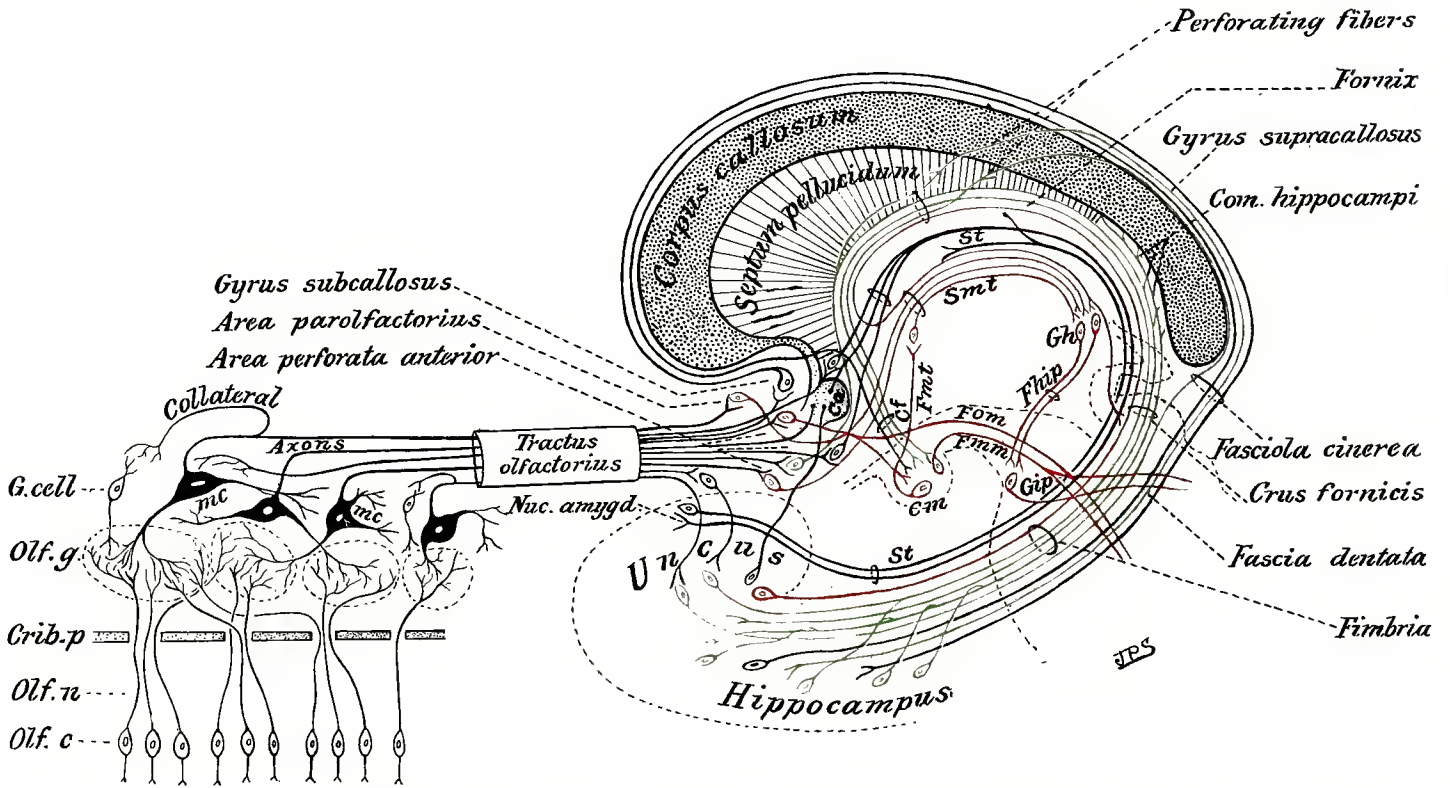

FIG. 202.—Schema of the principal connections of the olfactory apparatus.

G. cell = Granule cell; *Olf. g* = Olfactory glomeruli; *Crib. p* = Cribriform plate; *Olf. N* = Olfactory nerves; *Olf. c* = Olfactory cells; *Ca* = Commissura anterior; *Cf* = Columna fornicis; *Cm* = Corpus mammillare; *Fmt* = Fasciculus mammillothalamicus; *Smt* = Stria medullaris thalami; *St* = Stria terminalis (semicircularis); *Gh* = Ganglion habenulæ; *Gip* = Ganglion interpedunculare; *Fhi. p* = Fasciculus habenulo-interpedunculare; *Fom* = Fasciculus olfacto-mesencephalicus; *Fmm* = Fasciculus mammillo-mesencephalicus.

in front of the subcallosal gyrus, the posterior parolfactory sulcus intervening. Ventrally the parolfactory area is delimited by the anterior parolfactory sulcus (Fig. 203). The parolfactory area is grossly confluent with the olfactory trigone and the cingulate gyrus (gyrus cinguli).

The subcallosal gyrus (gyrus subcallosus; peduncle of corpus callosum) is a narrow band or lamina of the pallium found on the medial surface of the cerebral hemisphere just in front of the rostral lamina (lamina rostralis) and the terminal lamina (lamina terminalis); behind the parolfactory area of Broca; and below the rostrum of the corpus callosum. It is more or less fused above to the rostrum and is continuous around the genu of the corpus callosum with the supracallosal gyrus and to some extent with the cingulate gyrus. Ventrally the subcallosal gyrus in part passes laterodorsally on its way into the uncus and in doing so courses in a portion of the anterior perforated substance usually referred to as the *diagonal band* of Broca. The right and left subcallosal gyri are closely approximated in the mid-sagittal plane, the *median subcallosal sulcus of Retzius* alone intervening. As stated elsewhere, a few of the fibers of the median olfactory stria terminate about cell bodies within the subcallosal gyrus, others may course through it without synapse.

The supracallosal gyrus (gyrus epicallosus; stratum griseum) consists of a very delicate sheet of gray substance in immediate gross contact with the upper surface of the corpus callosum, laterally it merges with the cingulate gyrus, and ventrally it is continued as the subcallosal gyri (vide supra).

Three *longitudinal striæ* (striæ longitudinales) are the most conspicuous portions of the supracallosal gyrus, *e.g.*, the *medial* and *lateral longitudinal striæ.* Dorsally the thin supracallosal lamina with its striæ passes around the splenium of the corpus callosum and continues bilaterally as the *fasciola cinerea,* then as the *fascia dentata hippocampi* (Fig. 203). Some of the component fibers of the supracallosal gyrus arise from cell bodies located within the subcallosal gyrus, the parolfactory area of Broca, and the anterior perforated substance. These fibers assume a dorsal course within the longitudinal striæ and terminate in the dentate fascia and the hippocampal field. Other fibers leave the gray matter of the supracallosal gyrus and enter the longitudinal striæ, coursing both forward and backward. A few of the component fibers of the striæ are known to pierce the corpus callosum to join the fornix (see page 332).

The fascia dentata hippocampi (gyrus dentatus) is prolonged from the fasciola cinerea caudoventralward above the hippocampal gyrus

into the depression of the uncus where it forms an acute bend and is continued over the surface of the uncus for a greater or less distance as the *band of Giacomini.* The identity of the latter is ultimately lost on the lateral surface of the uncus. The free edge of the dentate fascia or gyrus is overlapped by the fimbria, the fimbriodentate fissure intervening, and presents a characteristic notched appearance, the result of many parallel grooves partially cutting it at right angles (Fig. 203). Below the dentate fascia or gyrus is the extremely rudimentary or in most cases obliterated hippocampal or dentate fissure. The latter is not a factor in the production of the hippocampus in man (vide infra).

The hippocampus (hippocampus major) is the curved, sickle-shaped ventricular eminence, about 5 cm. long, which courses throughout the length of the floor of the inferior cornu of the lateral ventricle. It begins as a narrow, low ridge dorsally at the termination of the body of the lateral ventricle where it is confluent with the posterior pillar of the fornix. Ventrally and inferiorly the hippocampus undergoes enlargement forming the ventricular surface of the uncus and presents from two to three secondary elevations, the *hippocampal digitations.* This causes a paw-like conformation, the *pes hippocampi.*

The hippocampus is covered by a thick layer of white substance—the *alveus*—which arises from deeper parts and is continued medially to become confluent with the *fimbria hippocampi.* The latter is folded, and its margin—the *tænia fimbriæ,* lies in a sense in the cavity of the inferior cornu and attached to the choroid plexus and the extremely delicate non-nervous floor of the choroidal fissure. It should, however, be recalled that the immediate boundary of the inferior cornu of the lateral ventricle is epithelium (ependyma) and that, strictly speaking, the only thing in the ventricular system is the cerebrospinal fluid.

The ventricular eminence (hippocampus) in man is formed by the hippocampal and dentate columns of cells pushing the ventricular surface into relief rather than by an invagination of the surface, usually referred to as the fissura hippocampi. Elliot Smith says: "There is no fissura hippocampi in the human brain." While this is true in the majority of specimens there are occasional partial hippocampal fissures encountered but seldom of sufficient depth to be a factor in the molding of the hippocampus.

The uncus appears as the thickened ventral extremity of the hippocampal gyrus, and ventrally and caudally is separated from the adjacent temporal lobe by the rhinal sulcus. Deeply the uncus is in juxtaposition to the anterior perforated substance, and as stated elsewhere, is connected

dorsally and medially with the fascia dentata hippocampi and the fimbria hippocampi. Moreover, the lateral olfactory stria in large measure ends in the uncus (vide supra). Despite the fact that the uncus is seemingly a part of the limbic lobe, in continuity with the hippocampal gyrus, Turner and Elliot Smith have established its relation with the rhinencephalon.

The fornix is the great bilateral association pathway, arched beneath the corpus callosum and confluent with the septum lucidum. It is concerned almost wholly with the rhinencephalon. It may be considered the chief fiber-pathway connecting the olfactory cortex located within the uncus and hippocampus with the habenular body of the epithalamus, the mammillary body of the hypothalamus, and secondarily with the thalamus and mid-brain. Moreover, the angle formed by the diverging posterior pillars (crura fornices) with the body of the fornix is crossed by the transverse fibers—the *transverse fornix* or the *hippocampal commissure*—whereby the right and left hippocampal regions are interconnected. Not infrequently the dorsal part of the body of the fornix and the transverse fornix are adherent to the under surface of the corpus callosum; again, a horizontal cleft, the so-called *ventricle of the fornix* (Verga's ventricle), may intervene. The crura or posterior pillars of the fornix are continued into the inferior cornua of the lateral ventricle as the fimbria hippocampi (see page 334). The anterior pillars end as such in the mammillary bodies of the hypothalamus, however, many of the fibers pass through them without termination in synapses, decussate to the opposite side, turn into the reticular formation and course to the mid-brain, pons, and probably to lower levels (see also, the tractus mammillopeduncularis, page 342). It is not deemed profitable in this connection to enter into a detailed description of the fornix. The foregoing will suffice to indicate the connections of the fornix as an important association pathway in the olfactory apparatus.

The septum pellucidum (septum lucidum) is the thin, vertical bilaminar partition between the anterior cornua of the lateral ventricles. It is attached above to the under surface of the corpus callosum, below and dorsally to the fornix, and ventrally to the reflected portion of the corpus callosum (Fig. 203). The septum pellucidum contains between its laminæ the *cavum septi pellucidi*—the so-called fifth ventricle. Each lamina of the septum consists of a stratum of degenerated gray matter next the cavity of the septum and a stratum of white matter next the ependyma of the anterior cornu of the lateral ventricle.

The septum pellucidum is in part concerned with the olfactory organ.

Some of the fibers of the supracallosal gyrus join the fornix ventrally by passing through the ventral and inferior part of the septum pellucidum. Moreover, a few fibers from the medial olfactory stria pass into the septum pellucidum and course by way of the fornix to the hippocampus. It appears that the posterior angle of the septum pellucidum contains a few commissural fibers which leave the body of the fornix and a few perforating fibers which come from higher levels, *e.g.*, from the stratum griseum and fasciculus cinguli.[1]

The habenular triangle (trigonum habenulæ) is the small triangular area delimited by the superior collicular body, the peduncle of the pineal body, and the pulvinar of the thalamus. This triangle contains the *habenular ganglion* (ganglion habenulæ)—an important olfactory reflex center. About the cell bodies terminate the fibers of the medullary striæ of the thalami of the same and opposite sides, the decussation taking place by way of the habenular commissure. The axons of the cells of the habenular ganglion are collected on the ventral aspect of the ganglion and give rise to the *fasciculus retroflexus of Meynert* which courses downward and forward in the tegmentum of the mid-brain, medial to the red nucleus, and ends as such by synapsing with cell bodies within the *interpeduncular ganglion.* The axons of the cell bodies of the latter ganglion form the tegmental bundle of Gudden which partly ends in the dorsal tegmental nucleus. The fibers of the bundle also establish relationships with Schutz's dorsal longitudinal bundle and with other association neurons in the neighborhood.

The medullary stria of the thalamus (stria medullaris thalami) is a bilateral band of nerve fibers which courses along the superomedial aspect of the thalamus subjacent to the *ependymal ridge*—the *tænia thalami.* Many of the fibers of the medullary stria end by synapsing with cell bodies within the habenular ganglion of the same side, others decussate in the habenular commissure and end by synapsing with cell bodies within the habenular ganglion of the opposite side. Moreover, it is believed that a few component fibers of the medullary stria fail of termination within the habenulæ and pass as such into the superior colliculus of the mid-brain, others into the posterior longitudinal bundle. Relationships are also established with association neurons of the midbrain.

[1] The cingulum (fasciculus cinguli) is an association pathway which begins in front in the vicinity of the anterior perforated substance, arches in front of, then over the corpus callosum to the splenium of the latter, where it curves forward and downward in relation with the hippocampal gyrus, the uncus, and the temporal lobe. The cingulum is contained within the basal part of the cingulate gyrus and is composed of a number of short tracts, which enter and leave it at short intervals. It is established that no long association fibers coursing the entire extent of the cingulum are present.

The majority of the component fibers of the medullary stria of the thalamus belong to the olfactory apparatus and are derived from three important sources: (a) fibers from the anterior perforated substance and the parolfactory area of Broca pass to the medullary stria and form a rather direct olfacto-habenular tract; (b) fibers from cell bodies within the anterior nucleus of the thalamus bend into the medullary stria, forming a thalamo-habenular pathway; and (c) fibers leave the fornix and recurve into the medullary stria. These fibers are axons of nerve cell bodies within

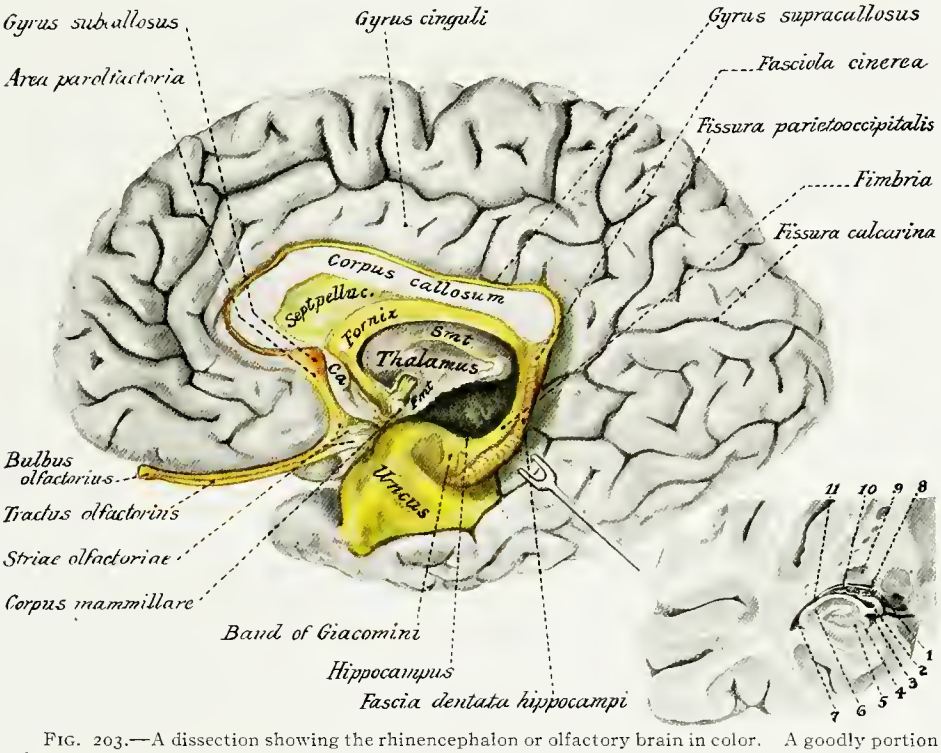

FIG. 203.—A dissection showing the rhinencephalon or olfactory brain in color. A goodly portion of the thalamus is removed and other portions of the brain drawn aside so as to expose the fimbria, hippocampus, etc.

Ca = Commissura anterior; *Smt* = Stria medullaris thalami; *Fmt* = Fasciculus mammillo-thalamicus (Vicq d' Azyr).

The inset in the lower right hand corner is a frontal section from the lower end of the inferior horn of the lateral ventricle and related structures.

1 = Choroidal fissure; 2 = Fimbria; 3 = Fimbrio-dentate fissure; 4 = Rudimentary hippocampal fissure; 5 = Dentate gyrus; 6 = Hippocampus; 7 = Inferior horn of lateral ventricle; 8 = Tenia semicircularis; 9 = Tail of caudate nucleus; 10 = Choroid plexus; 11 = Ependymal lining investing the choroid plexus and lining the horn of the ventricle.

the hippocampus and uncus. They are often referred to as the cortico-habenular tract (Fig. 202).

The mammillary bodies (copora mammillaria) are the round, white bodies which lie side by side in the interpeduncular fossa, behind the stalk

of the hypophysis and immediately in front of the posterior perforated substance. The bodies have an ectal covering of white substance largely derived from the columns of the fornix, and their interiors contain gray nuclei with many cells. The mammillary bodies have important olfactory connections; *e.g.*, the columns of the fornix, the fasciculus mammillothalamicus and the fasciculus mammillopeduncularis. Through some of these paths olfactory impulses reach the brain stem and probably the spinal cord, thereby influencing the skeletal muscles.

The stria terminalis (tænia semicircularis) is a bilateral narrow, ribbon-like band of white substance located in the sulcus between the caudate nucleus and the thalamus and according to Dejerine is connected with the olfactory sense.[1] Both the anterior perforated space and the septum pellucidum yield fibers to the stria. It is also believed that the anterior cerebral commissure adds a few components to it from the opposite olfactory lobe. Most of the fibers of the stria terminalis continue dorsally in the interval between the caudate nucleus and the thalamus, leave the body of the lateral ventricle and descend within the roof of the inferior cornu of the same and in intimate topographic relationship with the tail of the caudate nucleus to terminate in the *amygdaloid nucleus* (nucleus amygdalæ). Moreover, the stria terminalis contains fibers which arise from cell bodies located within the amygdaloid nucleus. These fibers oppose the others as regards direction, and after coursing for a greater or less distance as components of the stria they pass (a) to the thalamus and (b) to the internal capsule and cerebral cortex.

The *amygdaloid uucleus* is located in the ventral portion of the temporal lobe and in most intimate topographic relationship with the uncus. Indeed, the nucleus appears to be a detached portion of the uncus.

Olfactory Reflex and Cortical Connections.—As previously stated the cell bodies of the olfactory neurons of the first order are located in a small area of the nasal mucous membrane. The axons or central processes of these neurons pass through the cribriform plate of the ethmoid bone in approximately twenty bundles (the olfactory nerves, collectively the olfactory nerve), and terminate by free arborizations in the primary olfactory center (reception nucleus) within the olfactory bulb. As a rule, several olfactory nerve fibers and one or more dendrites of the mitral cells form entanglements of fibers known as the *olfactory glomeruli.* Here the first synapse in the olfactory pathway occurs (Fig. 202).

The arrangement of the neurons and their mode of synapse within the olfactory bulb may lead to strong excitations in the olfactory centers

[1] The stria terminalis is not infrequently referred to purely as an association pathway.

even though the peripheral olfactory stimulation be feeble. As shown in the diagram (Fig. 202), two or more olfactory nerve fibers may synapse with the dendrites of a single mitral cell, thus providing for the summation of stimuli in a single mitral cell. Furthermore, in addition to forming component fibers of the olfactory tract, the axons of the mitral cells give off collateral branches which synapse with the granule cells (small neurons of the olfactory bulb), which granule cells discharge among the dendrites of the mitral cells. This arrangement causes the discharge from the mitral cells to be enhanced.

The mitral cells are of the second order in the olfactory neuron chain, and, as stated above, their central processes (axons) collectively form the olfactory tract. The latter extends dorsally and divides into three distinct paths, the medial, intermediate, and lateral olfactory striæ, to terminate in various portions of the olfactory area or the secondary olfactory center and at points beyond.

The *medial olfactory stria* curves medially and most of its component fibers terminate about cell bodies located within the parolfactory area of Broca. Relatively few fibers are found to end within the substance of the anterior perforated space and the related portions of the septum pellucidum. Moreover, it is well established that the right and left olfactory bulbs are connected, the fibers of communication coursing by way of the medial olfactory stria and decussating in the anterior cerebral commissure, forming its *pars olfactoria* (see also page 343).

The *lateral olfactory stria* is the particularly prominent root of the olfactory tract, receiving most of its fibers. This stria is not infrequently referred to as the lateral olfactory gyrus. It curves dorsolateralward and its component fibers cross the anterolateral portion of the anterior perforated space into which a few fibers sink to terminate about its cell bodies. Equally few fibers find their termination in the olfactory trigone. The vast majority of the fibers of the lateral olfactory stria, however, pass beyond and penetrate the uncus to establish synapse relations with cell bodies found within this complicated and chief olfactory cortical region. Moreover, the component fibers of the lateral olfactory stria in coursing over the subfrontal region on their way to the uncus, give off collaterals which establish synapse relations with cells of the related frontal cortex. The latter cells give off axons to the medullary stria of the thalamus and to the thalamus. Some of these fibers may reach the brain stem (pons and medulla).

The *intermediate olfactory stria* is the most indefinite of the roots of the olfactory tract. Most of its component fibers terminate within the

anterior perforated substance, while a few are doubtless prolonged beyond into the olfactory cortex (uncus).

The several nuclei of the *secondary olfactory center* (the primary olfactory center is located in the olfactory bulb) are (1) important *reflex centers where olfactory and other sensory impulses are correlated* and (2) *centers for the discharge of olfactory impulses into the olfactory cerebral cortex.* It is believed that each nucleus of the olfactory area has an individual physiologic pattern complex. Ludwig Edinger believes that the intermediate nucleus, for example, especially in some mammals, is concerned with the feeding reflexes of the muzzle or snout; including, therefore, touch, smell, taste, and muscle and tendon sensibility. To this function complex Edinger has applied the term "oral sense." The reader is referred to the appended works by Edinger[1] for full discussions. It would lead us too far afield to consider them here.

From the several portions of the secondary olfactory center go forth neuron pathways of the third order, some more or less direct, others tortuous, involved in olfactory reflexes and in carrying impulses destined to reach the olfactory cortical centers. Moreover, many fibers of the olfactory tract pass the secondary olfactory center without suffering termination in synapses, particularly those coursing via the lateral olfactory stria.

The reflex pathways from the secondary olfactory centers within the olfactory area, etc., pass in large measure to the *mammillary bodies of the hypothalamus* and the *habenular bodies of the epithalamus.* From these bodies issue neurons of the fourth order to connect with the motor centers of the brain stem, which in turn establish relations with the nuclei of origin of cranial nerves and seemingly with the ventral horn cells of the upper spinal cord as well. Through these relations the most varied reflex movements are accomplished following olfactory excitation. The studies of Herrick[2] have led him to believe that in the epithalamus the olfactory nervous impulses are correlated with those of the somatic sensory centers of the thalamus (optic thalamus), especially the optic and the tactual systems; while in the hypothalamus they are correlated with the gustatory and the various visceral (sympathetic) sensory systems. Moreover, as

[1] Vorlesungen uber Bau der nervosen Zentralorgane Vergleichende Anatomie des Gehirns, Leipzig, Bd. 2, 1908.

The Relations of Comparative Anatomy to Comparative Psychology, Journal Comparative Neurology, Vol. XVIII, pp. 437–457, 1908.

Ueber die Oralsinne dienenden Apparate am Gehirn der Sauger, Deutsch. Zeits. f. Nervenheilkunde, Bd. 36, 1908.

Vorlesungen uber den Bau der Nervosen Zentralorgane Des Menschen und der Tiere, Leipzig, 1911.

[2] Introduction to Neurology, Philadelphia, 1916.

stated above, the secondary olfactory center discharges also into the olfactory cerebral cortex, the hippocampus and uncus.

The *olfactory cortical centers* give off association pathways for connection with other parts of the cerebral cortex, thus bringing the varied functional systems into interrelation with olfaction. Moreover, from the olfactory cortex, especially the hippocampus, issues a motor (efferent) pathway which courses by way of the fimbria, the several portions of the fornix and the striæ medullares thalami to reach both the hypothalamus and the epithalamus. From the latter points connections are established with the motor center in the cerebral peduncles, etc., by the same pathways that are involved in olfactory reflexes. Efferent or motor impulses (of cortical origin) in which the olfactory element prevails follow the efferent neuron pathway from the olfactory cortex above referred to, and by projection and association pathways reach the motor centers in the cerebral peduncles within the mid-brain, the nuclei of origin of the several cranial nerves, and the cell bodies of the motor spinal nerves located in the ventral horns. Such acts as motions of the alæ of the nose, sniffing, turning the head and body aside when breathing unpleasant and irritating odors may be explained by such neuron pathways. Obviously, it is at times difficult to separate actions which are the result of olfactory reflexes from voluntary motor actions resulting from efferent impulses in which the olfactory element predominates.

Olfactory Pathways.—The more important connections of the olfactory apparatus may be briefly summed up as follows (Fig. 202):

(A) An afferent conduction path conveys olfactory impulses from the olfactory mucous membrane to the primary olfactory center located within the olfactory bulb. From here the impulses follow the olfactory tract and either pass directly to the olfactory cortical centers or are transferred, within the secondary olfactory center, to neurons of the third order, the axons of which likewise terminate in the olfactory cortex. It will be recalled that the greater number of the axons of the mitral cells after coursing in the olfactory tract are prolonged into the lateral olfactory stria and terminate in the uncus, a few axons terminating within the olfactory trigone and the anterior perforated substance. While the uncus and the hippocampus contain the important cortical centers for smell, the amygdaloid nucleus also is believed to be part of the olfactory cortex. It is connected with the secondary olfactory center by the tract known as the stria terminalis or tænia semicircularis (see page 338).

(B) The several portions of the secondary olfactory center are important olfactory reflex stations. Tracts arising from the secondary

center pass directly to the tuber cinereum, the mammillary body, the habenular ganglion, the brain stem, and in all probability the spinal cord. While the reflex paths from the secondary olfactory center to the lower portions of the brain stem and spinal cord are but partially known, the following tracts appear established:

1. The direct *tractus olfactotegmentalis* (tractus olfactomesencephalicus, basal olfactory bundle of Wallenburg) arises from cell bodies located within the anterior perforated substance, the olfactory trigone, the cortex of the olfactory tract, and the septum pellucidum. The tract courses more or less direct to the tuber cinereum, the mammillary body, the motor centers of the brain stem, and, according to some investigators, to the spinal cord. Some of the fibers of the olfactotegmental tract penetrate the mammillary body and are believed to establish relationships with the contained nerve cell bodies, the latter giving rise to the tractus mammillopeduncularis.

2. The *tractus mammillopeduncularis* (fasciculus mammillotegmentalis, the mammillotegmental bundle of Gudden) connects the mammillary body with the motor centers of the mid-brain within the cerebral peduncles and the gray substance of the cerebral aqueduct. Moreover, a few fibers of the mammillopeduncular tract are believed to enter the posterior longitudinal bundle.

3. The *tractus olfactohabenularis* arises from cell bodies located within the parolfactory area and the anterior perforated substance and passes through the inferior segment of the septum pellucidum, and with other fibers (tractus corticohabenularis, etc.) forms the *stria medullaris thalami* (see page 337 for the component fibers of this stria). The medullary stria of the thalamus terminates by synapses in the habenular nucleus of the same and opposite sides (see page 336). Moreover, it is known that a few fibers of the medullary stria fail of termination within the habenular nucleus and continue beyond into the superior collicular (quadrigeminal) body and the association and projection pathways of the mid-brain, including the posterior longitudinal bundle.

4. The *tractus habenulopeduncularis* (fasciculus retroflexus, Meynert's bundle) issues from the cell bodies of the habenular nucleus and connects the latter with the interpeduncular ganglion located within the posterior perforated substance in front of the pons between the cerebral peduncles.

5. The *tractus tegmentalis* (tegmental bundle of Gudden) arises from the cell bodies of the interpeduncular nucleus, courses dorsocaudalward and some of its fibers end in the red nucleus, others come into relationship with Schutz's dorsal longitudinal bundle and other association neurons of the tegmentum of the mid-brain.

6. The tractus mammillothalamicus (tract of Vicq d'Azyr) connects the mammillary body with the anterior nucleus of the thalamus for the correlation of the olfactory with the general somatic reactions. The tract of Vicq d'Azyr is formed by axons arising from the cell bodies of the medial and lateral nuclei of the mammillary body and by some of the fibers continued from the anterior pillar of the fornix which fail to suffer synapse terminations within the mammillary body.

(C) Efferent fibers, the axons of the pyramidal cells of the uncus and the hippocampus and the variously shaped cells of the related dentate fascia of the hippocampus, leave the cortical olfactory centers by way of the fimbria. Approximately twenty-five per cent. of these efferent fibers are continued into the fornix proper, for distribution to the habenular ganglion, the mammillary body, the brain stem, and points below. Moreover, axons arising from nerve cell bodies within the amygdaloid nucleus course via the stria terminalis (tænia semicircularis), opposing in direction the afferent components of this stria, and enter the thalamus, others pass into the internal capsule and to the cerebral cortex above (see page 338).

The efferent fibers from the olfactory cortex are to be thought of as olfactory associational and projection fibers. Of those that enter the fornix proper, some leave the latter and join the stria medullaris thalami (see page 337) for the habenular nuclei and the mid-brain, others pass to the mammillary body via the corresponding anterior pillar of the fornix, either to terminate in this body or to pass through it.[1] The fibers that fail to terminate in the mammillary body either cross to the opposite side and become component fibers of the tractus mammillopeduncularis or enter the tract of Vicq d'Azyr (probably of both sides). It will be recalled that the former passes in the reticular formation to the mid-brain, pons and probably to points at lower levels.

(D) Commissural tracts connect the two sides of the olfactory apparatus. Approximately seventy-five per cent. of the fibers which leave the uncus, the hippocampus and the related dentate fascia by way of the fimbria (see above) are distinctly smaller than the remaining association and projection fibers, and are commissural in character. They course in the fimbria, but instead of being continued into the fornix proper pass by way of the *hippocampal commissure* (transverse fornix, lyre, ventral psalterium) to the fimbria and hippocampus of the opposite side, thereby connecting the olfactory cortices of the two sides. Moreover, the anterior cerebral commissure contains a small *olfactory fasciculus* which connects the ol-

[1] Despite the fact that many fibers pass through the mammillary body, synapse relations are established with the cells in loco by collaterals from the fibers.

factory bulbs of the two sides—true commissural fibers—and the olfactory bulb of one side with the uncus of the other side. According to Van Gehuchten,[1] however, none of the fibers of the anterior commissure arise from the nerve cells located within the olfactory bulb. He believes that the olfactory portion of the commissure is an association system connecting the olfactory cortex of one side with the olfactory bulb of the other.

The Relations of the Brain to the Walls of the Nasal Fossæ and the Paranasal Sinuses.—But brief mention of the anatomic naso-encephalic relations need be made here since reference to the relationships is made in the foregoing chapters. This is especially true for the meningeal relations, the hypophysis cerebri and the cavernous sinus.

The olfactory bulb and tract lie in very close relation with the roof of the nasal cavity. While the olfactory bulb usually rests more or less freely upon the cranial surface of the lamina cribrosa of the ethmoid bone, it is at times markedly encroached upon by the dorsomedial extension of the frontal sinus, by a cell in the crista galli, or by ethmoidal cells. Frequently such encroachments merely lead to a crowding of the olfactory bulb in one direction or another. When, however, these sinus and cell extensions occur simultaneously the olfactory bulb may be pinched upon to a marked degree (Fig. 200). The author is unable to say whether this has any bearing upon atrophy of the olfactory bulb or upon the physiology of smell.

The frontal sinuses come into relationship with the brain cortex in the neighborhood of the pole of the frontal lobe. It is essential in this connection to recall the extensive pneumatizations of the frontal sinus that are not infrequently encountered (Figs. 113 and 114). Naturally, the brain exposure is in accord with the size of the frontal sinus.

The ethmoidal cells lie opposite the gyrus rectus and usually come into relationship with the basal cortex for a goodly distance lateral to the gyrus rectus. Dorsally the sphenoidal sinus replaces the ethmoidal cells in this relationship. While the sphenoidal sinus is usually separated laterally from the brain cortex by the intervening cavernous sinus, it occasionally pneumatizes beneath and lateral to the cavernous sinus and comes into most intimate relationship with the temporal lobe of the brain (Fig. 142). It is, therefore, possible for an abscess of the temporal lobe to arise from a diseased state of the sphenoidal sinus.

An appreciation and knowledge of the relations and variations of the paranasal sinuses are alone of value in the localization of rhinogenic brain abscesses of paranasal origin.

[1] Le Nevraxe, 1904.

XII—PHYSIOLOGICAL ADDENDA

CHAPTER XII

PHYSIOLOGICAL ADDENDA

The Nose Proper.—The functions of the nose proper are of divers sorts. Only small portions of the definitive or adult nasal fossæ are specifically olfactory in function (see the peripheral olfactory organ, page 325). The remaining and greater portions of the nasal fossæ conjointly serve the rôle of an adjunct respiratory organ despite the fact that the primitive or primary nasal fossæ and their derivatives are wholly olfactory in their physiology. The respiratory rôle is purely secondary as is evidenced by the embryology and comparative anatomy of the nose (see Chapter I). The nasal cavity serves ancillary rôles in connection with audition, taste, and the proper production of voice; moreover, serves as a drainage cavity for the paranasal sinuses and the nasolacrimal apparatus. The nasal mucous membrane in its normal condition is supposed to have certain bactericidal properties, whereby the nasal fossæ become defensive organs against the invasion of bacteria by way of the inspired air. The external nose very frequently reproduces to a marked degree family and racial characteristics and through the attachment of facial muscles modifies facial expression.

It is generally believed that the current of air in passing through the nasal fossæ does not pursue a straight course, but passes in curves and eddies. This leads to a prolonged stay of the air within the nasal cavity; moreover, aids in the dissemination of the air into the various recesses, etc., of the very irregularly configured lateral nasal walls. The foregoing are important factors in warming and moistening the air before it passes into the nasopharynx. The great vascularity of the nasal mucous membrane and the secretions of the nasal glands are the prime factors in supplying heat and moisture to the inspired air. By the time the air has reached the larynx it is normally warmed to blood temperature and laden with moisture. The erectile tissue of the nose is especially active and undergoes engorgement when the air is dry, thereby providing the necessary moisture. When the inhaled air is humid the erectile tissue is less active. It has been estimated that in twenty-four hours over a liter of water is normally supplied by the nose and that when the functions of the

latter are impaired there is a dryness and tendency to catarrh in the nose, pharynx, trachea, etc. (Figs. 159, 181 and 183).

The nose normally acts as a filter for particles of dust and bacteria with which the inhaled air is laden. The vibrissæ located in the nasal vestibules entangle many of these and keep them from reaching the nasal mucous membrane proper. The vestibules are always laden with microörganisms (mostly non-pathogenic); fewer are found in the nasal fossæ and fewer still in the nasopharynx. Dust particles and microörganisms which reach the nasal fossæ and paranasal sinuses are normally expelled by the action of the ciliated epithelium and the secretion of the nasal glands. The activity of phagocytes is, doubtless, also a factor. The current produced by the ciliated epithelium of the nasal fossæ is toward the nasopharynx and that of the paranasal sinuses is toward the ostia of the sinuses, therefore, toward the nasal fossæ. This was confirmed by the author by placing powdered carbon on the mucous membranes of the paranasal sinuses in a number of animals. The observation showed that the carbon particles were carried into the nasal fossæ and from there into the nasopharynx.

While the active bactericidal property of the secretion of the nasal glands is questioned by some, it is doubtless established that it has at least a marked inhibitory influence on the growth of microörganisms. This is equally true of the paranasal sinuses. Thomson and Hewlet found when cultures of non-pathogenic organisms are artificially introduced into the nose they disappear rapidly.[1] This probably accounts for the great abundance of microörganisms in the nasal vestibules and for their relative scantiness in the interior of the nasal fossæ and their almost total disappearance in the upper portions of the pharynx. Bertarelli and Calamida[2] claim that the paranasal (accessory) sinuses, in animals at least, are always sterile. Torne[3] found the paranasal sinuses of human bodies just dead to be sterile. In a later observation[4] he, however, found bacteria present, indicating that the inspired air carries microörganisms into the paranasal sinuses. It is, however, definitely known that the paranasal sinuses are not the conspicuous habitat for microörganisms as was one time generally believed. Two prominent physiologic factors come into play in ridding the nasal fossæ and its related paranasal sinuses of bacteria: first, the action of the ciliated epithelium and second, the apparent bactericidal or surely inhibitory properties of the nasal mucus. Should these defensive

[1] Med.-Chir. Trans., Vol. 78, 1895.

[2] Archivio Itilano di Otologica, Vol. 13.

[3] Nord. Med. Arkiv., H. 1, 1904.

[4] Central. f. Bakteriologie, Bd. 33, 1903.

mechanisms be overcome by invading bacteria, infection of the nose and paranasal sinuses is, of course, inevitable. Phagocytes and solitary lymph nodes of the nasal mucosa may be additional protective agencies. St. Clair Thomson in commenting upon the bactericidal functions of the secretion of the nasal glands emphasizes the importance of respecting the erectile tissue portions of the nasal mucous membrane; arguing that "it is better to be a partial mouth-breather than to have free nasal passages with their protective mechanisms seriously damaged."

The nasal cavities exert a profound influence upon vocalization. The sound-vibrations which arise in the larynx and ascend in the pharynx require a resonating chamber for the realization of a full and clear sonorous tone of the human voice; for some sounds this chamber is found in the ever open nasopharynx and the nasal fossæ with their posterior and anterior apertures. If the nasal fossæ or their apertures are blocked by pathologic conditions, marked changes in some of the fundamental sounds are encountered. The soft palate likewise is of importance in this connection—its movements must be free and unimpeded. The voice of every individual has a peculiar quality, clang or timber. This is dependent upon the shape, size and health of the cavities connected with the larynx. In nasal tones the air in the nasal fossæ vibrates freely, necessitating, therefore, free nasal fossæ and apertures. The nasal timber is produced by the soft palate (palatum molle) not shutting off completely the nasal fossæ, happening when pure vowels are sounded with a resultant sympathetic vibration of the air in the nasal fossæ. It has been shown that "when a vowel is spoken with a nasal timber, air passes out of the nose and mouth simultaneously, while with a pure vowel sound, it passes out only through the mouth." Hartmann has demonstrated that it requires an artificial pressure of 30 to 100 mm. of mercury to overcome the soft palate when sounding a pure or non-nasal vowel, so complete is the physiologic occlusion between the oropharynx and the nasopharynx. The vowels, a, ä (æ), ö (œ), o, e, are used with a nasal timber. Strictly speaking a nasal i does not occur in any language since it is next impossible to sound it as such under normal conditions, since the bulk of the air passes out through the nasal fossæ and their apertures. According to their mechanism of formation consonants may be divided into explosives, vibratives, aspirates, and resonants. In the sounding of the latter group the nasal fossæ are entirely free, while the oral aperture is shut off; therefore, they are frequently called nasals or semi-vowels. In the former three groups the nasal cavity is entirely shut off.

The foregoing will suffice to show the importance of healthy and nor-

mal nasal fossæ in vocalization. The reader is referred to the special treatises on voice and sounds for more detailed discussions. It would lead us too far afield to undertake it here.

The Paranasal Sinuses.—Various functions have been ascribed the paranasal sinuses, some of which are unwarranted, others purely hypothetical, while a third group are suggestive and within the field of probability. It is not profitable, however, in this connection to speak of the many theories that have been advanced, suffice it to speak of those that appear tenable.

The author is of the firm opinion that until the phylogenic beginning of the paranasal (accessory) sinuses is more definitely established the functions of the cavities must necessarily remain more or less obscure. Indeed, the initial functions of the sinuses may have been entirely replaced by secondary functions in man. Comparative anatomy has, of course, given some light and further study in this direction is essential. It is not an easy task to map out accurately the olfactory field in a large series of mammals. The embryology or ontogenetic history of the paranasal sinuses is well known for a number of forms (see Chapter I for man), but what is especially wanted now is the phylogenetic history.

It would appear certain that the paranasal sinuses are old in their phylogeny since they begin their ontogenetic development relatively early in the human embryo (see pages 36 to 37). This belief is supported by the recent observations of Moodie[1] who had the opportunity of studying the casts of the paranasal sinuses of two early tertiary mammals—oreodont[2] (Merycochoerus) and an early bear-dog (Daphaenus). The casts made by nature and preserved in fossil form indicated an enormous development of the frontal and maxillary sinuses. A study of the casts leads Moodie to believe that the origin of the paranasal chambers "is to be found, not in the early mammals, but in their ancestors, and probably their remote ancestors." Descriptive paleontology may indeed prove a valuable supplement to comparative embryology, anatomy and physiology in an effort to solve the real meaning of the paranasal sinuses, both primitive and recent.

Smell is evidently the dominant sense in very many of the lower vertebrates. This is evidenced by the great development of the olfactory brain and the behavior of such animals. In man and other primates the olfactory organ is much reduced and the olfactory sense relatively very rudimentary (see page 328). As stated elsewhere, in accordance with the

[1] On the Sinus Paranasales of Two Early Tertiary Mammals, Jour. Morph., Vol. 28, 1916.

[2] Leidy speaks of the genera of the Oreodontidæ as "ruminating hogs."

degree of development of the olfactory apparatus, one may distinguish between mammals which are macrosmatic (most of the mammalian orders), microsmatic (seals, whalebone-whales, and primates, including man), and anosmatic (most toothed-whales). In Mammalia, except in Monotremata, the nasal fossæ communicate with one or more paranasal chambers; *e.g.*, the maxillary, frontal, and sphenoidal sinuses (the three sinuses are not necessarily present in all forms). In some forms that have been carefully studied *olfactory folds* are enclosed in the paranasal sinuses mentioned, especially the frontal and sphenoidal. With the reduction of the olfactory sense in other forms there is a resultant loss of the primary olfactory function of the sinuses—a pneumatic and purely secondary rôle being assumed. Indeed, the sinuses may disappear altogether; witness, for example, Pinnipedia (seals, walruses). The maxillary is the most constant of the sinuses, being typical for Eutheria, and the only sinus present in Insectivora and bats.

The author is of the opinion that the paranasal sinuses of man no longer fill the rôle initially set for them in their phylogenetic history. There is considerable evidence that the olfactory mucous membrane was much more extensive at one time. Indeed, as indicated above, it is more extensive in many of the lower mammals. The fact that the entire embryonic nasal fossæ of man (see page 47) are *initially* olfactory in their character, *e.g.*, in their embryonic development, would seem to indicate that phylogenetically the olfactory nasal mucosa was more extensive than it is in the post-embryonic human nose. The respiratory rôle of the human nasal cavity is clearly secondary. In all likelihood, therefore, in the phylogeny of the human nose, the olfactory mucosa primarily extended into the derivatives of the nasal fossæ, *e.g.*, certain of the paranasal sinuses; this in order that the area of the olfactroy mucosa be increased and a correspondingly more acute sense of smell provided. Man and the anthropoids not requiring the strong sense of smell for their existence and survival became macrosmatic (possessing smell in a comparatively feeble degree); the respiratory field of the nasal mucous membrane gradually encroaching upon the olfactory field and reducing it to the limited area in the upper portion of the nasal fossa; moreover, the olfactory elements becoming completely lost to the paranasal sinuses.

Strictly speaking, the olfactory nature of the ethmoid cells cannot be argued since the ethmoid labyrinth is not present as such in most macrosmatic or acutely smelling animals. In these forms the ethmoid field assumes a great complexity and maze of endo- and ectoturbinals, enclosing within their scroll-like folds portions of the nasal fossa. These

fossa-inclusions can, however, not be spoken of as "ethmoid cells," since the latter designation connotes an entirely erroneous conception of these structures both as to their genesis and real anatomy. The ethmoid labyrinth, composed of sinuses or cells not unlike the frontal, maxillary and sphenoidal sinuses, reaches its perfection as such in some of the anthropoids and man. Despite the phylogenetically late appearance of true ethmoidal cells, the ethmoidal labyrinth as found in man simulates in a measure the very complex field of ecto- and endoturbinals with nasal-cavity inclusions of acutely smelling or macrosmatic animals. The scroll-like inclusions of the turbinal field of macrosmatics are in a sense analogous to the cells of the ethmoidal labyrinth of man and certain anthropoids. However, it must be strictly understood that they are not morphologically homologous. The great reduction of the ethmoidal field in man naturally precludes the formation of inclusions of the nasal fossa save to a limited extent (see the furrows of the middle meatus, pages 28–35). The direct outgrowth of the nasal mucosa in the formation of the ethmoidal cells and the pneumatizaton of the ethmoid and neighboring bones is the nearest approach to the complicated scroll-like formations of macrosmatic animals.

Since smell is a chemically excited sense requiring a solution of the gaseous odoriferous substances in the moisture of the olfactory mucous membrane before the olfactory receptors are stimulated, it was obviously necessary from the phylogenetic beginning of the paranasal chambers that air passes into them in order that the olfactory elements might be stimulated. It is, therefore, clear that, while the olfactory function of the sinuses may have been primary, the rôle as pneumatic cavities and adjuncts to respiration was perforce equally primitive.

With the withdrawal of the olfactory functions in the phylogenetic development of the sinuses in man, the one conspicuous and probably dominant function remaining is that as an adjunct to respiration, particularly to aid in humidifying and warming the inspired air. It has been definitely established, especially by Braune and Clasen, that during respiration there is a certain amount of air change in the paranasal sinuses. The degree of interchange of air is obviously more or less dependent upon the size and freedom of the ostia of the respective sinuses and the amount of air inspired. Good ventilation of the paranasal sinuses is essential to health and is normally maintained. Pathologic states in the nasal fossæ may seriously block the interchange of air by encroachment on the ostia of communication between the sinuses and the nasal fossæ.

A number of investigators support the theory that in order to have proper equipoise of the head it is necessary that some of

its bones be pneumatized. Such pneumatization is found in the paranasal sinuses and from this is inferred that the main function of the sinuses is to lighten the bones of the skull. Braune and Clasen[1] particularly have opposed such function in view of the fact that, according to their studies, but one per cent. would be added to the weight of the skull should the pneumatic cavities be replaced by spongy bone. Their contention would merit more support if the pneumatization of the head bones should be equally distributed. It, however, happens that practically the entire system of pneumatic cavities is located in the ventral portion of the head. It appears plausible, therefore, should the paranasal sinuses be replaced by solid bone, that the poise and equipoise of the head would be markedly interfered with, since the head with the contained sinuses is very evenly balanced. The argument, that the theory of lightness and balance of the skull as related to the paranasal sinuses fails because children have no sinuses yet are able to balance their heads, is not permissible, since children do have fairly well developed sinuses even at birth.

It is very unlikely that the paranasal sinuses exert any influence upon vocalization. The ostia of the sinuses are so small and not infrequently encroached upon by neighboring parts that one naturally wonders how the chambers can have any modifying influence on the sound waves. Moreover, the great variations in the size and arrangement of the sinuses would preclude any constancy of influence. The theory that the paranasal sinuses impart resonance to the voice must, doubtless, be abandoned

In view of the fact that the mucous membranes of the paranasal sinuses are very sparsely supplied with glands, the theory that the dominant function of the sinuses is to supply moisture in the form of mucus to the nasal fossæ is archaic and unwarranted, since a very limited amount of moisture is thus supplied.

Under normal conditions the paranasal sinuses are capable of self-drainage. All of them are lined by a ciliated epithelium, with a wave-like ciliary motion directed toward the ostia of the sinuses. It must, however, be recalled that in the human nose the maxillary and sphenoidal sinuses and certain of the ethmoidal and conchal cells have no gravity drainage. Most of the ethmoidal cells and the frontal sinuses have their ostia so located that gravity itself is a material factor in freeing the sinuses of accumulated mucus. Of course, when the position of the body is changed from the erect posture to the horizontal, or better when the head is placed with its vertex downward, the maxillary, sphenoidal and conchal cells likewise

[1] Zeit. f. Anat., Bd. 2, 1877.

have a gravity drain. This discrepancy in the location and relations of the ostia of the several sinuses accounts for the dissimilarity of the subjective symptoms (other things being equal) in diseased states of the individual sinuses.

Olfactory Sensation.—The development and complexity of the olfactory lobes of the cerebrum and the nasal fossæ in mammals vary greatly and are in accord with the degree of acuity of the sense of smell. Of course, the immediate intensity of the olfactory sensation depends on the size of the olfactory fields in the nasal fossæ, the concentration of the odoriferous substance and the frequency of the conduction of the substance by sniffing to the olfactory receptors. Certain animals have no sense of smell (anosmatic) including certain cetaceous mammals like the porpoise and toothed whale, the olfactory nerve being absent. Rarely there is congenital anosmia in man. In other mammals the sense of smell is remarkably acute (macrosmatic), including rodents, carnivora, marsupials and other mammals. Moreover, there is an intermediate group of animals which possess smell in a comparatively feeble degree (microsmatic), including most primates, monotremes, some cetacea and man. Since the olfactory function warns the individual of offending gases, the olfactory organ assumes the additional rôle of a protective organ.

In spite of the fact that man is microsmatic his sense of smell is normally aroused by inconceivably dilute solutions of odoriferous substances—one part of mercaptan to thirty billions of air being detectible. Valentin reports that $\frac{3}{100,000,000}$ of a grain of musk can be distinctly smelled. Camphor is perceived in a dilution of 1 part to 400,000. It is known that the acuteness of the sense of smell can be greatly improved by practice. The case of James Mitchell, who though deaf, dumb and blind, distinguished persons and objects by his acutely trained sense of smell, is often referred to in this connection. The delicacy of the sense of smell varies normally in different individuals. The threshold of excitation is much lower for smell than it is for taste owing to the suppression of a synapse in the peripheral olfactory receptors in the nasal mucosa and to peculiarities in the neuron synapses in the olfactory bulb (page 338). The olfactory organ responds to a much larger range of chemical stimuli and to greater dilutions than does the gustatory organ. Parker and Stabler[1] have shown that the human olfactory organ responds to alcohol at a dilution 24,000 times greater than that necessary to activate the organ of

[1] On Certain Distinctions between Taste and Smell, Amer. Jour. Physiol., Vol. XXII, pp. 230 to 240.

taste. The interrelations between taste and smell are, however, very important (vide infra). Strangely the olfactory receptors are almost as readily fatigued as they are excited and the sense of smell soon becomes untrustworthy as an organ for the detection of odoriferous substances. Many inhaled substances after a brief period cease to produce a detectible sensation. The normal individual readily notices the unpleasant odor upon entering an ill-ventilated room, yet after the lapse of a few minutes ceases to perceive it because of the fatigue of his olfactory apparatus. A completely fatigued apparatus recovers, however, in a very short time, provided the environment is suitable.

It would appear established that smell in man, as probably in all present vertebrates, has both exteroceptive and interoceptive qualities. Despite the fact that primitively smell was an interoceptive sense it is now dominated by the exteroceptive quality. However, some of its initial quality persists. As Herrick states, the somatic reactions are obviously more important than the visceral responses.

Smell like taste is a chemically excited sense. It requires a solution of the gaseous odoriferous substances in the moisture of the olfactory mucous membrane before the olfactory receptors are stimulated. The mucous membrane must be neither too moist nor too dry for the most favorable reaction. Strangely all gaseous substances do not stimulate the olfactory receptors, and it is assumed according to Howell and others that there are certain odoriphore groups which are characteristic of all odoriferous substances and by virtue of which these substances react with the special form of protoplasm found in the olfactory hair cells. Halliburton says that generally the odors of homologous series of compounds increase in intensity with increase of molecular weight, but bodies of very low molecular weight are odorless, while vapors of very high molecular weight, which escape and diffuse slowly, have little or no smell.

The passage of odoriferous substances to the olfactory receptors is accomplished by mere diffusion or by the act of sniffing which produces currents of air and intensifies the sensation. The peripheral localization is very imperfect since individuals confound many smells with tastes. Many flavors (tastes) are really smells, the odoriferous substances which are being eaten in all probability reaching the peripheral olfactory organ through the choanæ, and since they accompany the presence of food or other particles in the mouth are interpreted as gustatory sensations rather than olfactory. Indeed, it is well known to everyone that blocking of the choanæ (posterior nares) by a nasopharyngeal pathology and the nares and nasal fossæ by a coryza loses much flavor value of foods to the in-

dividual. Physicians and mothers well know that compressing the nares (nostrils) of the little rebellious patient makes easier the administration of certain drugs by mouth—much of the so-called "taste" of the medicine is destroyed thereby.

Many attempts have been made to discover the fundamental or elementary sensations of smell as has been satisfactorily done for taste (sour, salty, sweet, bitter). Ordinarily individuals are content to speak of olfactory sensations as agreeable or pleasant and disagreeable or repulsive. In addition to these Haller suggested a third—the mixed. It is held by some that the agreeable or disagreeableness of the olfactory sensations (odors or smells) is in many instances dependent upon the olfactory associations connected with them, *i.e.*, if the associative memories aroused are unpleasant the odor is repulsive or disagreeable and vice versa. One of the most complete classifications of odors is given by Zwarrdemaker.[1] He classifies them into (1) pure odors, (2) odors confused with taste and (3) odors mixed with common sensibility of the mucous membrane of the nose. These primary groups are subdivided into secondary groups. It is well known, for example, that ammonia a pungent substance, stimulates the endings of the trigeminal nerve as well as those of the olfactory nerve. The so-called taste of spices is not perceived when the nose is compressed and the nares closed off, a certain pungency alone being experienced, due to a stimulation of the nerves of general sensation. If, however, the nose is freely open "taste" is experienced which is in reality smell.

When two odoriferous substances are simultaneously inhaled, one may be dominant and the other secondary or entirely suppressed in the consciousness. On the other hand, one of the odors may be perceived and after a very brief pause the other, or the two odors may be perceived as a mixed odor and be unlike either of the elementary odors. Some odoriferous substances readily fatigue the olfactory receptors in the nasal mucosa. However, the receptors may be fatigued by one substance, yet be acutely sensitive and active to others. This leads one to think of either a selective power of the units composing the peripheral olfactory organ or that some substances affect some portion of the olfactory mucosa, while others affect other parts. It is, of course, well known that the organ is variously sensitive to different odoriferous substances.

As stated elsewhere the cortical olfactory center located in the hippocampus and the uncus is widely connected with other parts of the cerebrum. These connections serve as an anatomic basis for the extensive association connected with the odors. Olfactory sensations often awaken powerful

[1] Die Physiologie des Geruchs, Leipsig, 1895.

multitudinous associations of memory and as Howell[1] aptly says, "our olfactory memories are good."

It has long been observed that obvious important relationships exist between the olfactory and the sexual organs. In animals with highly developed olfactory organs, both vertebrate and invertebrate, the olfactory sense is intimately connected with the sexual reflexes (see also page 296). Moreover, a remnant of such relationships is very apparent among human beings. Howell[2] rightly states that "among the so-called special senses that of smell is the one most closely connected with the bodily appetites, and over-gratification or over-indulgence of this sense, according to historical evidence, has at least been associated with periods of marked decadence of virtue among civilized nations."

There exists also apparently a physiologic and pathologic relationship between the non-olfactory nasal mucosa and the sexual organs. It is said that inflammations of the nasal fossæ and the paranasal sinuses exercise a marked influence over the sexual functions. (See Chapter X for a fuller discussion.) The author recently learned of a few individuals in whom during every sexual excitement the glands of the nasal mucous membrane pour forth a voluminous amount of mucous which subsides at once with the completion of the sexual act. This is, of course, a psychic condition, supporting the thesis that there is a cortical center which acts on the glandulosecretory and vasodilator centers (see page 293).

Little is known on the heritability of differences in the sense of smell. Blakeslee[3] has shown that two individuals may exhibit marked degrees of sensitivity to the fragrance of verbena flowers. He found in tests that one individual not infrequently would declare one of two blossoms emitting a fragrant odor and the other not, while a second individual on judging of the same blossoms would declare the exact opposites as regards the fragrance of the blossoms. Glaser[4] recently observed an individual, A, who was quite unable to distinguish odors in the usual way and whose history showed among his immediate sibs two sisters normal as regards olfaction, one brother the exact counterpart of A, and another with but slight capacity for the detection of odors. The mother of A was unable to detect odors and her father was similarly deficient. A careful study indicated that there were certain resemblances to sex-linked inheritance. The fact that the trait has appeared in one collateral (A's cousin is defective in the sense of smell and is the daughter of a paternal aunt who is

[1] Textbook of Physiology, Philadelphia, 1914.

[2] Loc. cit.

[3] Science, N. S., Vol. 48, 1918.

[4] Science, N. S., Vol. 48, 1918.

anosmatic) and two direct generations, is believed by Glaser to be sufficiently frequent to warrant the assumption that anosmia is heritable. Moreover, he believes that anosmia is probably to be placed in the list of sex-linked characters since two sisters of A are reported to be normal as regards olfaction.

It is reasonably certain that defects in the sense of smell are inherited in human beings, especially so since the function of olfaction is degenerate and vestigial as compared with other forms. Not infrequently there is a striking difference in the sense of smell on the two sides of the same individual. Again, the function may be entirely suppressed. While anosmia is, doubtless, inherited at times, one must ever be cautious not to confuse anosmia due to diseased states of the olfactory mucosa, the olfactory bulb and tract or of the olfactory cortex with a truly congenital anosmia. Careful examination of the nasal fossæ by a trained rhinologist, including both macroscopic and microscopic studies, is essential in anosmatics. In many instances such study will place previously believed congenital anosmatics on the side of the acquired type and the result of nasal disease.

Strangely the condition of anosmia seems to be inbred in some localities which suggests that certain nasal disorders are especially prevalent, leading to diseased olfactory mucosæ with a resultant suspension of smell. The author doubts that anosmia is sex-linked in inheritance since it occurs in both women and men. It would, however, seem that congenital anosmia is more frequently encountered in males. The reason for this is unknown. However, until the records of a large series of cases show a decided advantage in favor of men, it is unwise to assume that anosmia is sex-linked in inheritance.

Functional anosmia is occasionally encountered. Wheeler in the Bulletin of the Canadian Army Medical Corps, records an interesting case of complete functional loss of smell in a soldier who was buried by an explosive shell, April, 1917. The soldier recovered with the gustatory sense normal for the four primary tastes. He was incapable, however, of recognizing his food, having lost that fine discrimination with which taste and not smell has usually but erroneously been credited. Following electrical treatments the olfactory function returned and the patient was again able to recognize odors. His foods once more "tasted" normal and appetizing.

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